CHAPTER 6

DISTRIBUTION AND ABUNDANCE OF FOSSORIAL ANIMAL BURROWS IN THE APWRA AND THE EFFECTS OF RODENT CONTROL ON BIRD MORTALITY

6.1 INTRODUCTION

The distribution and abundance of California ground squirrels *(Spermophilus beecheyi)* in the APWRA is of interest to researchers because they are a major prey species for golden eagles (Hunt and Culp 1997; Hunt et al. 1998; Curry and Kerlinger 2000; Environmental Science Associates 2002; Hunt 2002; Kerlinger and Curry 2003). Proponents of rodent control in the APWRA believe that reducing raptor prey populations in the APWRA through intensive control of California ground squirrels might discourage raptors from visiting the APWRA, and thus might reduce the number of raptor fatalities caused by wind turbines (Kerlinger and Curry 1999; Hunt 2002; Kerlinger and Curry 2003).

During the course of our studies, we noted that many raptors were killed south of Altamont Pass Road. This was in an area where by 1999 intense rodent control had nearly completely eradicated ground squirrels. We suspected that other prey species for raptors may occur there, or that the relationship between raptor visitation to a site and that site's ground squirrel occurrence was misunderstood.

Pocket gophers *(Thomomys bottae)* are abundant throughout the APWRA, but ground squirrels have an uneven, patchy distribution, as we demonstrate with data in this report. Red-tailed hawks and great horned owls rely heavily on pocket gophers (Fitch et al. 1946; Craighead and Craighead 1956; Orians and Kuhlman 1956), whereas golden eagles rely more heavily on larger prey such as ground squirrels and lagomorphs (Carnie 1954; Olendorff 1976). California vole *(Microtus californicus)* populations likely also influence the distributions of raptor species, as likely do small reptiles, amphibians, and arthropods, which are fed upon by burrowing owls and American kestrels, as examples. Pocket gopher burrows provide habitat for most of these additional raptor prey species. While there is some overlap, each raptor species using the APWRA likely pursues a somewhat different suite of prey resources.

Pocket gopher burrow systems typically occurred immediately adjacent to wind turbines (Photo 6-1), whereas ground squirrel burrow systems were often located farther away (Photos 6-2 and 6-3). Therefore, it occurred to us that raptors flying close to operating wind turbines might not be approaching to hunt ground squirrels, but rather to hunt pocket gophers and other species that associate with pocket gopher burrow systems. These early observations lead to an expanded line of research.

In alfalfa stands in the Central Valley, raptors spend a disproportionately large fraction of their flight time directly over pocket gopher burrow systems, where K. S. Smallwood (unpublished data) has observed raptors capturing pocket gophers, voles, snakes, and black-tailed jackrabbits. Assuming the same may be the case in the APWRA, we decided to map the locations of pocket gopher and ground squirrel burrow systems in and around selected strings of wind turbines.

Photo 6-1. Pocket gopher burrow systems (see the light-colored mounds) typically occurred near wind turbines, such as along the cuts made into hillsides for wind tower laydown areas and access roads.

Photo 6-2. Ground squirrel burrow systems typically occurred on slopes below wind turbines located on ridge crests, such as those seen in this photo.

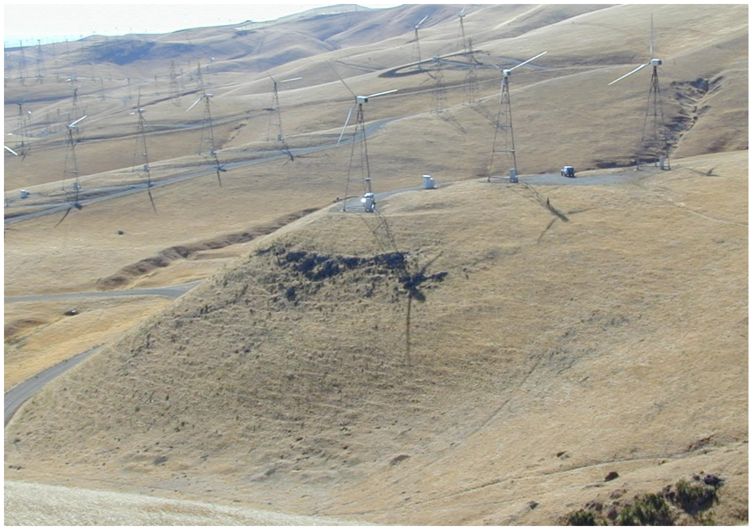


Photo 6-3. Ground squirrel burrow systems typically occurred on slopes below wind turbines located on ridge crests, such as to the lower left-center area in this photo.

Wind turbine operators in the APWRA controlled ground squirrels during or prior to 1997. Their consultants maintained data on where and how much effort was put into rodent control by the Alameda County agent who was funded by the turbine operators to implement the control program. We learned of this program in fall 2002, but we observed poison bait being dispensed throughout our study, beginning in 1998.

Our objectives for this research effort were to: (1) relate ground squirrel and pocket gopher distribution and abundance to the levels of rodent control intensity applied in the APWRA; (2) relate the distribution and abundance of these species to physiographic conditions, relevant turbine attributes, and season; and (3) compare the mortality of raptors to the densities and degree of contagion of burrow systems actively used by potential prey species around individual wind turbines and around turbine strings.

6.2 METHODS

We mapped rodent burrows near 571 wind turbines, composing 70 strings of wind turbines in the APWRA. Most wind turbine strings were selected arbitrarily, to represent a wide range of raptor mortality recorded during our fatality searches, as well as to represent a variety of physiographic conditions and levels of rodent control.

We had no control over the rodent control program. It was administered by the wind companies and carried out by Alameda County and some ranch owners. To characterize the levels of rodent control applied, we interviewed the Alameda County agent who dispensed the poison bait and was most familiar with the implementation of the program.

The rodent control applied in the APWRA has consisted of dispensing onto the ground rolled oats treated with 0.01% chlorophacinone, an anticoagulant. A truck was driven back and forth across treatment areas, and a dispenser broadcast the bait onto the ground. Two assistants walked over treated areas two weeks later and picked up dead animals lying on the ground. We were told that consultants to the turbine owners maintained a database on the number of ground squirrels picked up, but we were unable to obtain these data. In January 2004, we were provided copies of an unpublished report (Kerlinger and Curry 2003) on the rodent control program's effectiveness. A comparison of our results with those of Kerlinger and Curry (2003) appears in Appendix B to this report.

We mapped the approximate centers of pocket gopher, ground squirrel, and desert cottontail burrow systems using a Trimble Pathfinder Pro-XR GPS with an error rate < 0.5 m. We located burrow systems based on freshly excavated soil or scats at the burrow entrance, which indicated that the burrows were occupied. Although we easily recognized the boundaries of most individual pocket gopher and ground squirrel burrow systems, a pacing method (Smallwood and Erickson 1995) was used to separate burrows when continuity of sign rendered inter-burrow system distinctions difficult. We mapped burrows used by desert cottontails, kangaroo rats, burrowing owls, and mammalian carnivores as we encountered them.

Our search for burrows began within the string of wind turbines. A 15 m-wide strip transect was walked from 15 m beyond the wind turbine at one end of the string to 15 m beyond the wind turbine at the other end. Then perimeter transects were walked at 15, 30, 45, 60, 75, and 90 m away from the turbine string, thus covering increasingly larger areas around the turbine strings. These 15-m intervals correspond with the distance across the largest burrow systems of male pocket gophers (Smallwood and Erickson 1995). A laser rangefinder was used to maintain the intended distances away from the turbines while searching along perimeter transects.

The degree of clustering at wind turbines was estimated in two ways. In one, we estimated densities of gopher and ground squirrel burrow systems within each of the corresponding areas searched. Using least squares linear regression, densities of burrow systems were then regressed on the corresponding search areas and the steepness of the regression slope used as an indicator of contagion relative to the location of each string of wind turbines. Steeper inverse slopes indicated greater degrees of clustering at the wind turbines.

The other indicator of clustering near wind turbines was the observed divided by expected number of burrow systems within the 15-m zone of wind turbines, where the expected value was N burrows within 90 m multiplied by the ratio of the area in the 15-m zone to the area in the entire 90-m search area. Larger ratios of observed-to-expected number of burrow systems indicated greater degrees of clustering within 15 m of the wind turbines. Also, we estimated the density of burrow systems within 90 m of each string of wind turbines and compared these data to physiographic conditions, rodent control intensity, and other factors.

We learned *post hoc* about the rodent control in the APWRA. However, not all land owners participated with the program, which provided the basis for some fundamental comparisons. We divided the control intensity into three categories: none, intermittent, and intense. Information on where and how chlorophacinone-treated oats were dispersed in the APWRA was obtained by the

County's applicator. Using these data, we categorized specific wind turbines by the level of rodent control deployed per treatment area. Areas defined as having intermittent control were those not treated by the County but by the landowner in a manner that the County's field applicator felt was less systematic and less frequent than was done in ownerships we rated as receiving intense control. Some of the areas not treated through 2001 were treated in 2002; however, we considered these areas untreated in our comparisons, because rodent burrows were mapped previous to the treatments.

An edge index was measured from the string transect while viewing the 40–m radius from the turbine: 0 = no vertical or lateral edge within 40 m of the wind turbine; 1 = some lateral edge, such as the presence of a dirt road other than just the service road found at all of the wind turbines (Photo 6-4), or cleared area adjacent to vegetated area, or area tilled for pipeline, etc.; 2 = lots of lateral edge; 3 = some vertical edge, such as road cut, road embankment, or cut into the hillside for creating a flat laydown area for the tower pad; 4 = lots of vertical edge, covering half or more of the area within 40 m of the wind turbine; and 5 = lots of vertical and lateral edge within 40 m of the wind turbine. This index was related to burrow distributions to test whether burrowing animal species associate with vertical and lateral edge, as has often been suggested in the literature.

Photo 6-4. All wind turbines included access roads, but those in the foreground also were near regularly disked soil, either as a firebreak or over a pipeline. The wind turbine lowest on the slope would have been rated as having an index value for vertical and lateral edge. Turbines on the mid-slope have some vertical edge (and high index value for lateral edge), and those on the top of the slope have a high index value for lateral edge, but no vertical edge.

The densities and spatial distributions of burrow systems used by fossorial species were related to raptor mortality measured throughout the study period, as well as measured within a year of the date the burrows were mapped at the particular wind turbine string. Thus, mortality was measured nearer in time to the maps of burrow systems in the latter comparison, but it was measured more robustly while also expressed over more time in the former comparison. Mortality was measured as the number of fatalities recorded per megawatt of rated power output from the associated wind turbines per year, or deaths/MW/year.

6.3 RESULTS

6.3.1 Density and Distribution of Burrowing Animals

Pocket gopher burrow systems occurred within 90 m of all but one wind turbine string (Figure 6-1A), and the mean density of gopher burrow systems was less than that of ground squirrel burrow systems (Figure 6-1B). The density of ground squirrel burrow systems was often much greater than recorded pocket gopher burrow system density, but there were also 10 more study areas devoid of ground squirrels as compared to pocket gophers (Figures 6-1A and 6-1B). Two out of every three study areas lacked burrows of desert cottontail within 90 m of wind turbines and the mean density of cottontail burrows was low (Figure 6-2A). The density of burrow systems of all fossorial species mapped were approximately normally distributed among wind turbine strings (Figure 6-2B). Almost all areas that we searched lacked any burrowing owl burrows within 90 m of wind turbines during the summer (Figure 6-3).

As the density of pocket gopher burrow systems increased, it did so within 15 m of wind turbines at twice the rate as it did within 90 m of the wind turbines where rodent control was implemented, but not at all where rodent control was not applied (Figure 6-4A). Conversely, the density of ground squirrel burrow systems increased proportionally between 15 m and 90 m distances of wind turbines (Figure 6-4B), meaning that unlike pocket gophers, ground squirrels demonstrated no affinity for the areas within 15 m of wind turbines.

Desert cottontails showed the greatest affinity for the areas within 15 m of wind turbines, as the density of its burrows increased within 15 m of wind turbines at nearly four times the rate that it did within 90 m of the wind turbines (Figure 6-5).

Pocket gopher density consistently decreased as larger areas were searched around each string of wind turbines (Figure 6-6A), indicating that pocket gophers were clustered around the wind turbines. Nearly all turbine strings demonstrated a relationship between gopher burrow density and study area size that was similar to the pattern reported by Smallwood and Morrison (1999), which was an inverse power function. Similarly, most of the observed-divided-by-expected number of gopher burrow systems within 15 m of the wind turbines was greater than 1.0 (Figure 6-6B), meaning that gophers were almost always clustered to some degree around the wind turbines.

Because our regression-based index of clustering related precisely to the observed-divided-by-expected number of burrow systems within 15 m of the wind turbines (Figure 6-7), we opted to use the latter index throughout the remainder of this analysis. Another reason for our use of the latter index was that it enabled the inclusion of wind turbine strings with no pocket gophers within 90 m of the wind turbines, whereas the former index did not.

Based on the observed-divided-by-expected number of burrow systems within 15 m of wind turbines, ground squirrels on average appeared to avoid establishing burrow systems close to wind turbines (Figure 6-8A); whereas, desert cottontails selected these areas (Figure 6-8B). The collection of animal species studies showed a statistical preference for burrow establishment within 15 m of wind turbines (Figure 6-9).

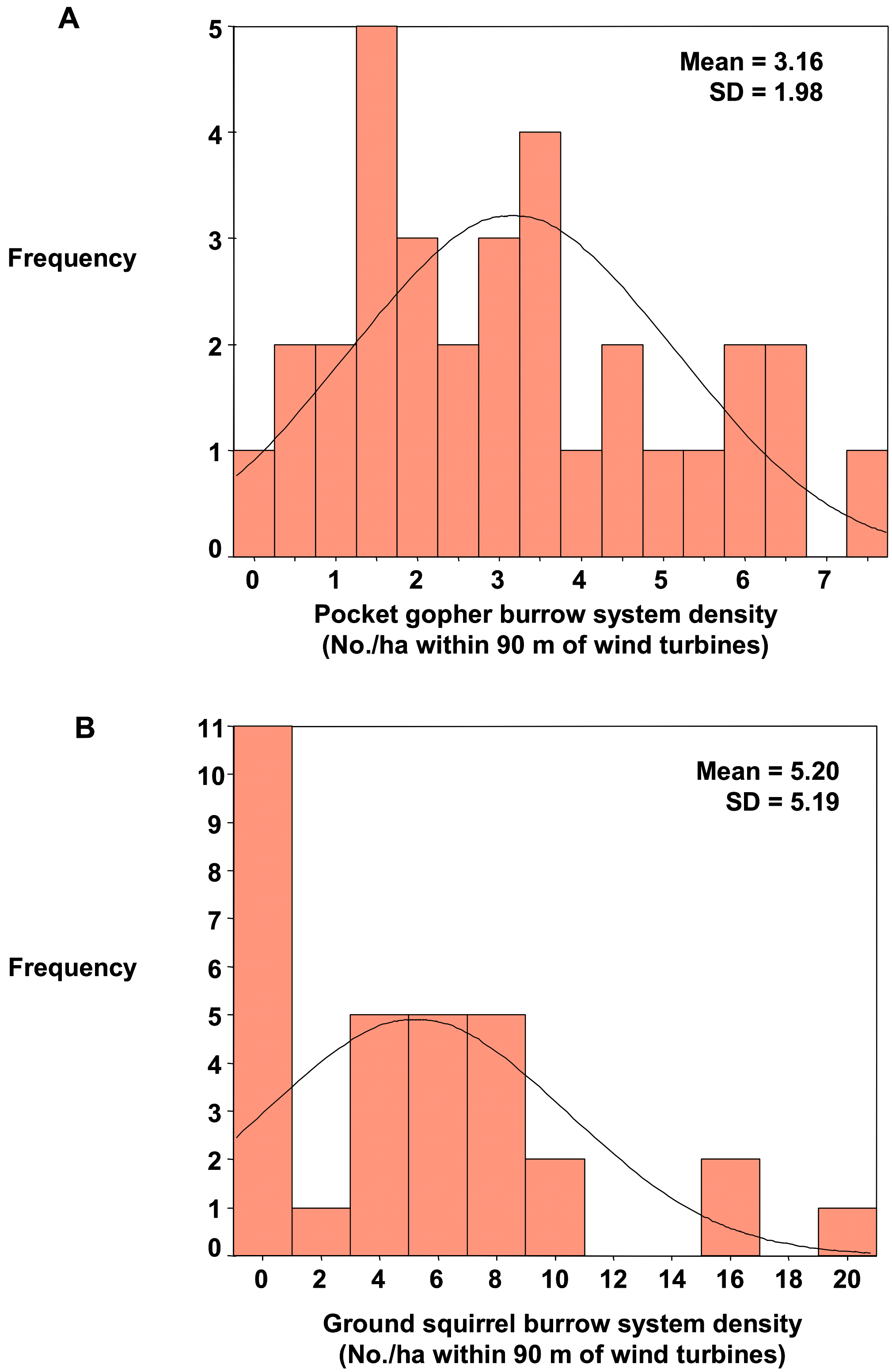


Figure 6-1. Frequency distributions of the density of burrow systems of pocket gophers (A) and ground squirrels (B) within 90 m of wind turbines

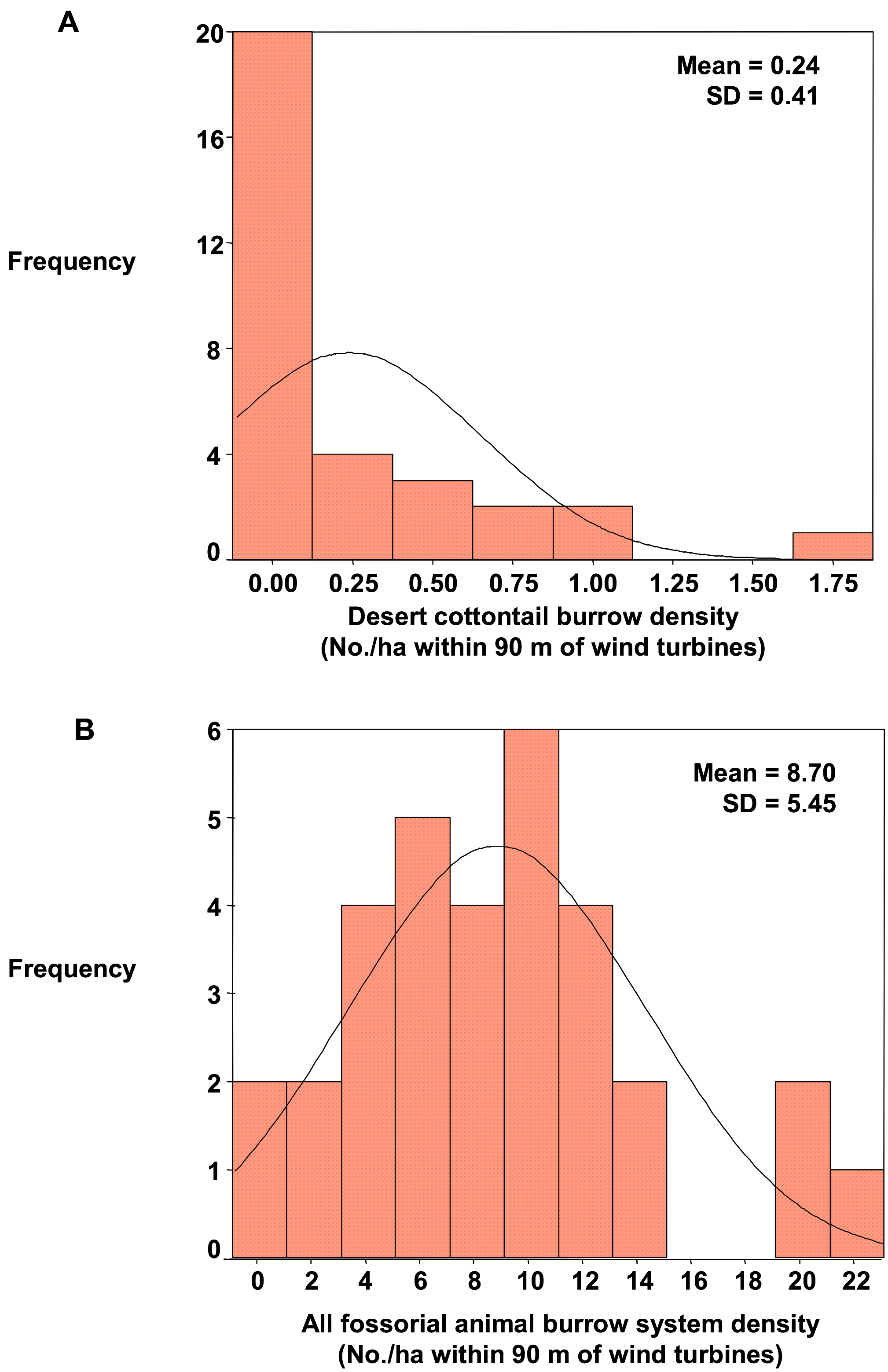


Figure 6-2. Frequency distributions of the density of burrow systems of desert cottontails (A) and all fossorial mammal species (B) within 90 m of wind turbines

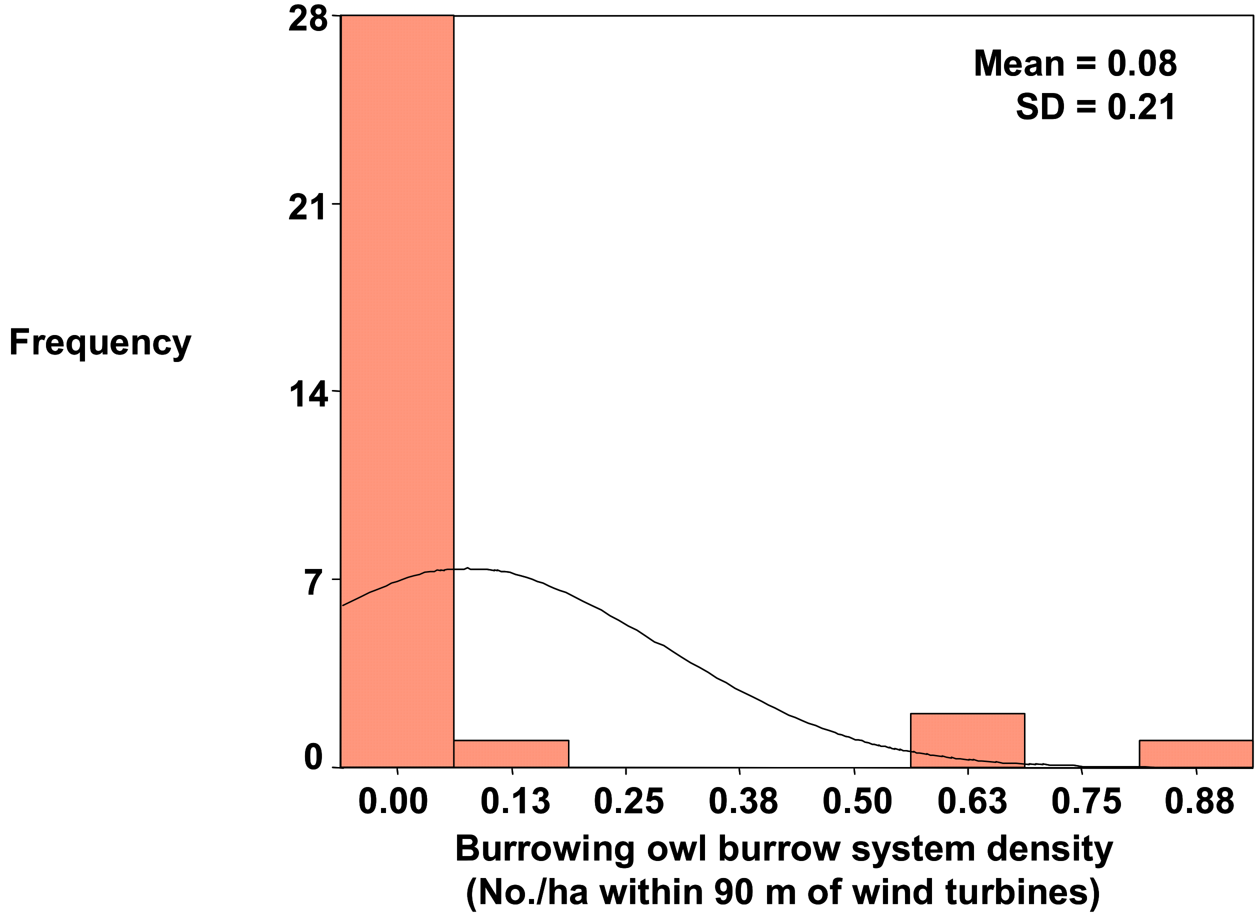


Figure 6-3. Frequency distribution of the density of burrowing owl burrows within 90 m of wind turbines

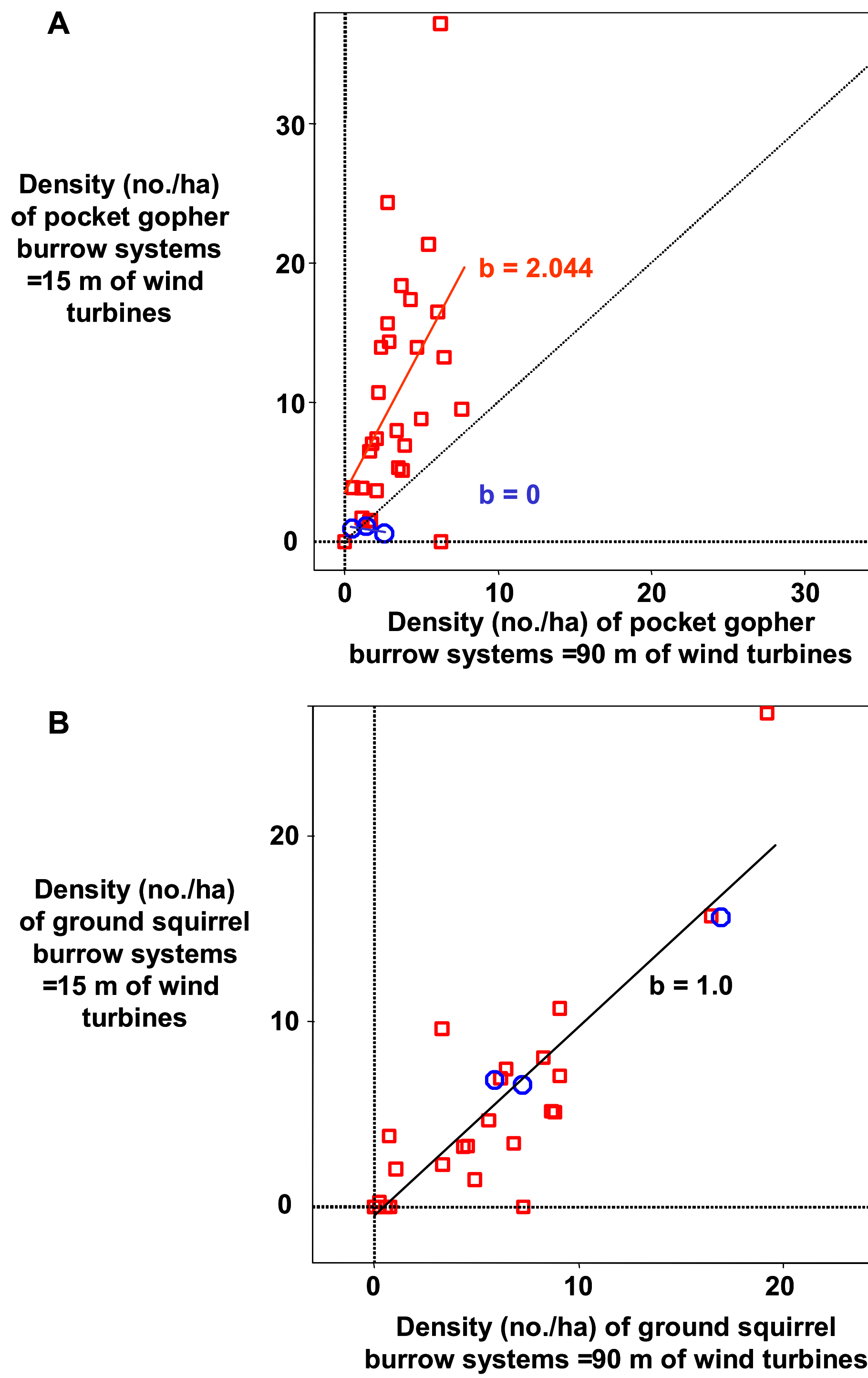


Figure 6-4. Density of burrow systems within 15 m of wind turbines related to density within 90 m for pocket gophers (A) and ground squirrels (B), illustrating the pocket gopher's greater affinity for the areas immediately next to the wind turbines. Blue circles denote the areas of no rodent control, and red squares denote the areas of rodent control. The letter "b" denotes the slope coefficient estimated by least-squares linear regression analysis.

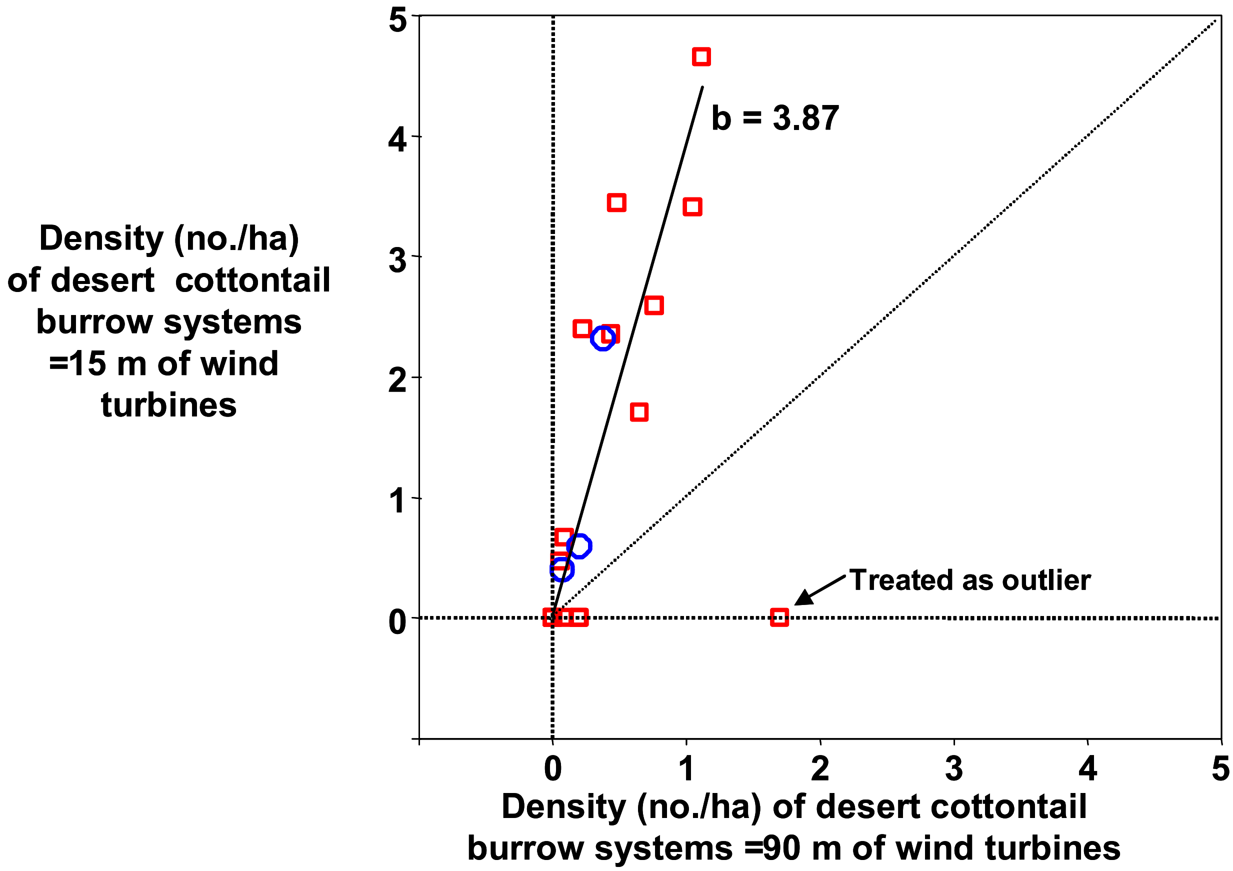


Figure 6-5. Density of desert cottontail burrow systems within 15 m of wind turbines related to density within 90 m. Blue circles denote the areas of no rodent control, and red squares denote the areas of rodent control. The letter “b” denotes the slope coefficient estimated by least-squares linear regression analysis.

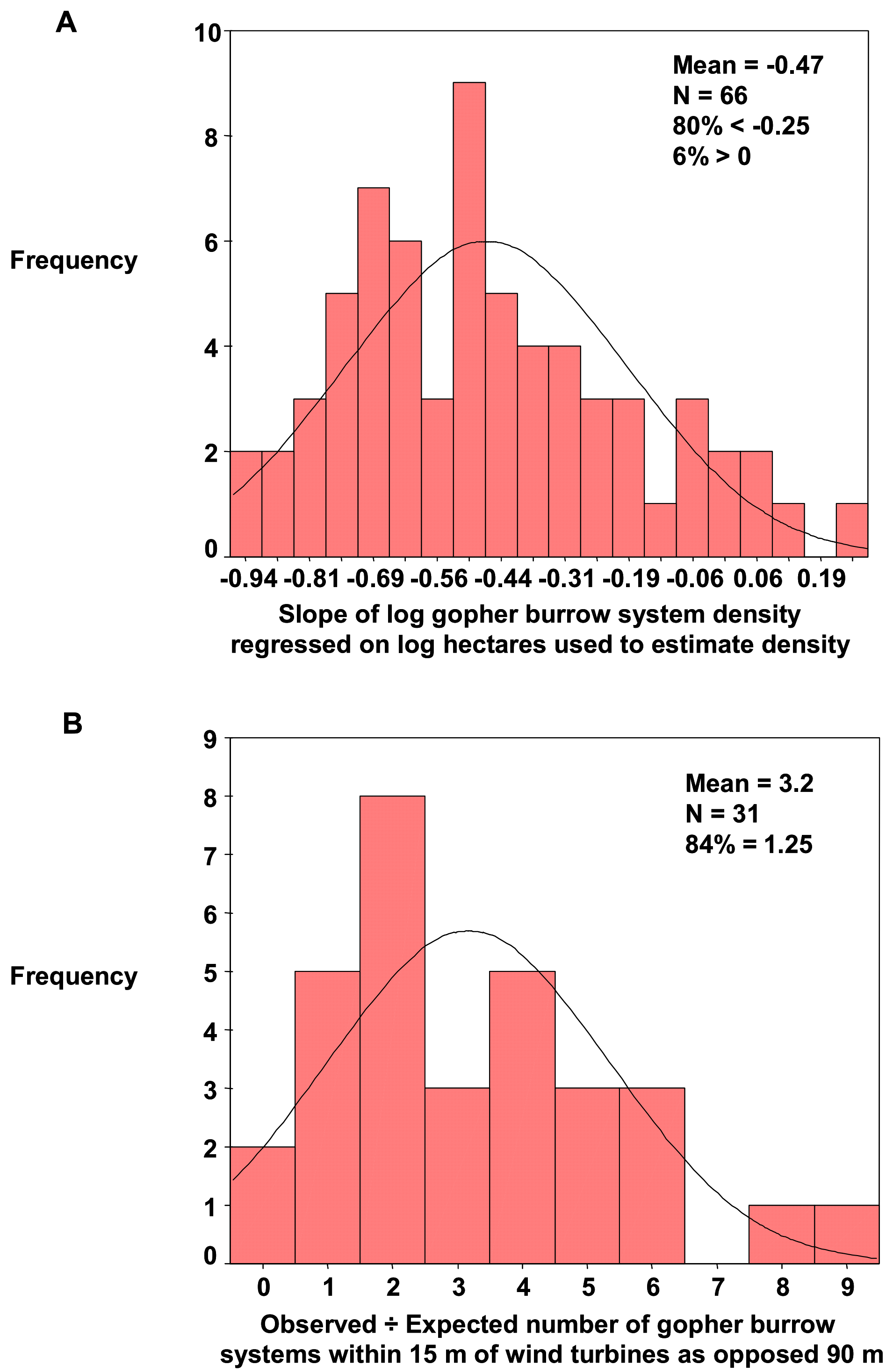


Figure 6-6. Frequency distributions of the degree of clustering of pocket gopher burrow systems at wind turbines represented by (A) the slope of log density regressed on log search area around each wind turbine string, and (B) the observed ÷ expected number of burrow systems within 15 m of the wind turbines, where strings of wind turbines were combined into groups when contiguous and mapped during the same year and season.

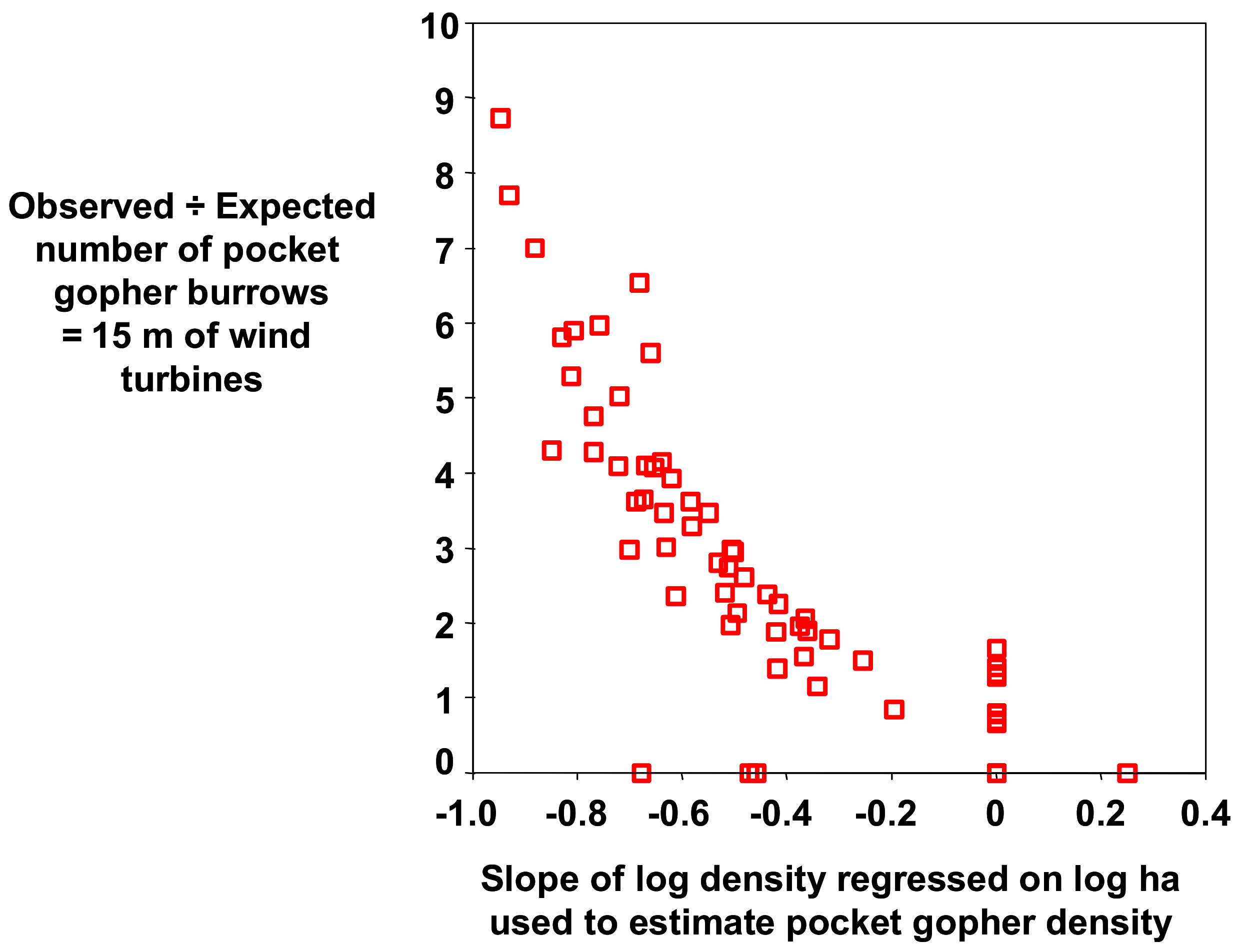


Figure 6-7. Relationship between two methods of characterizing the degree of clustering of burrow systems at wind turbines

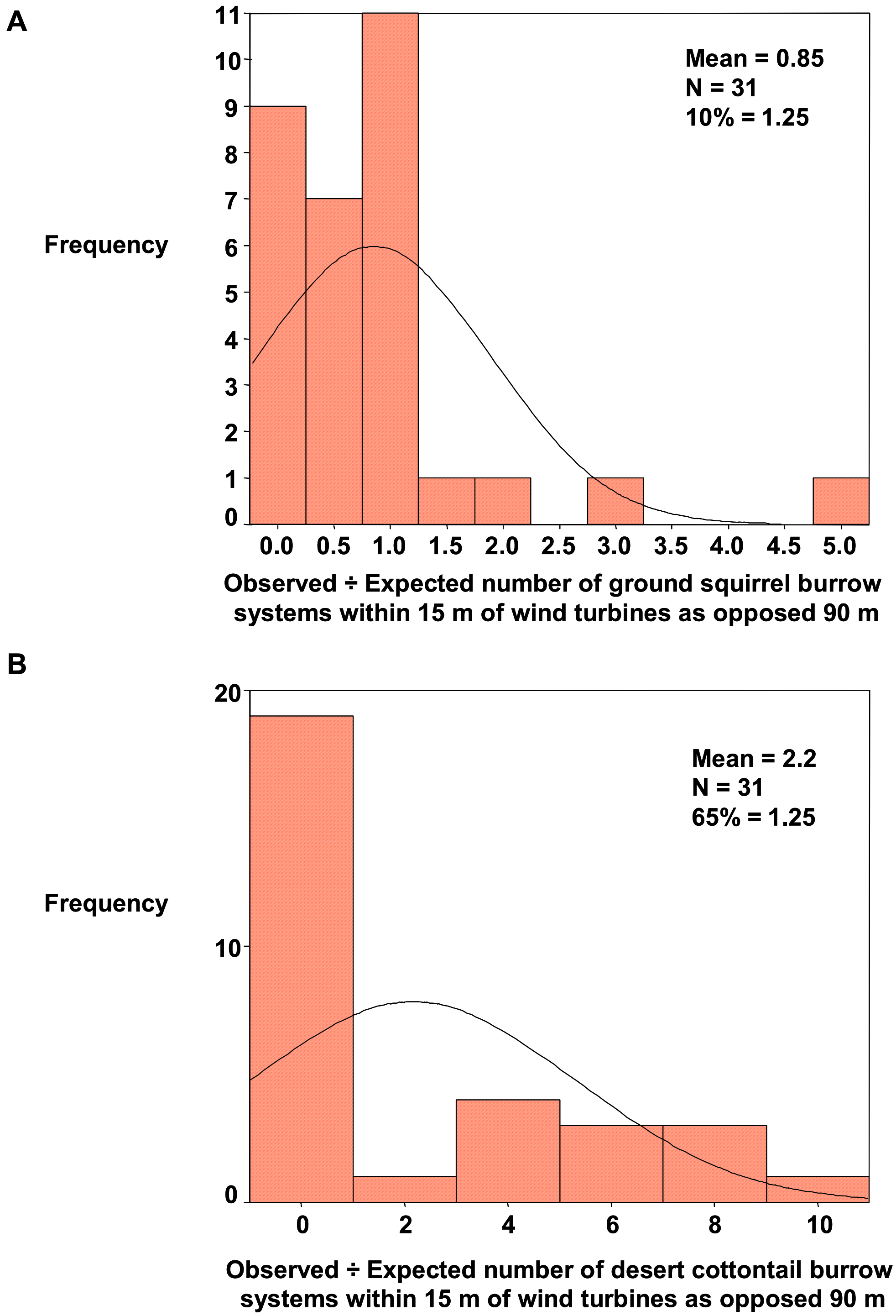


Figure 6-8. Frequency distributions of the degree of clustering of ground squirrel (A) and desert cottontail (B) burrow systems around wind turbines

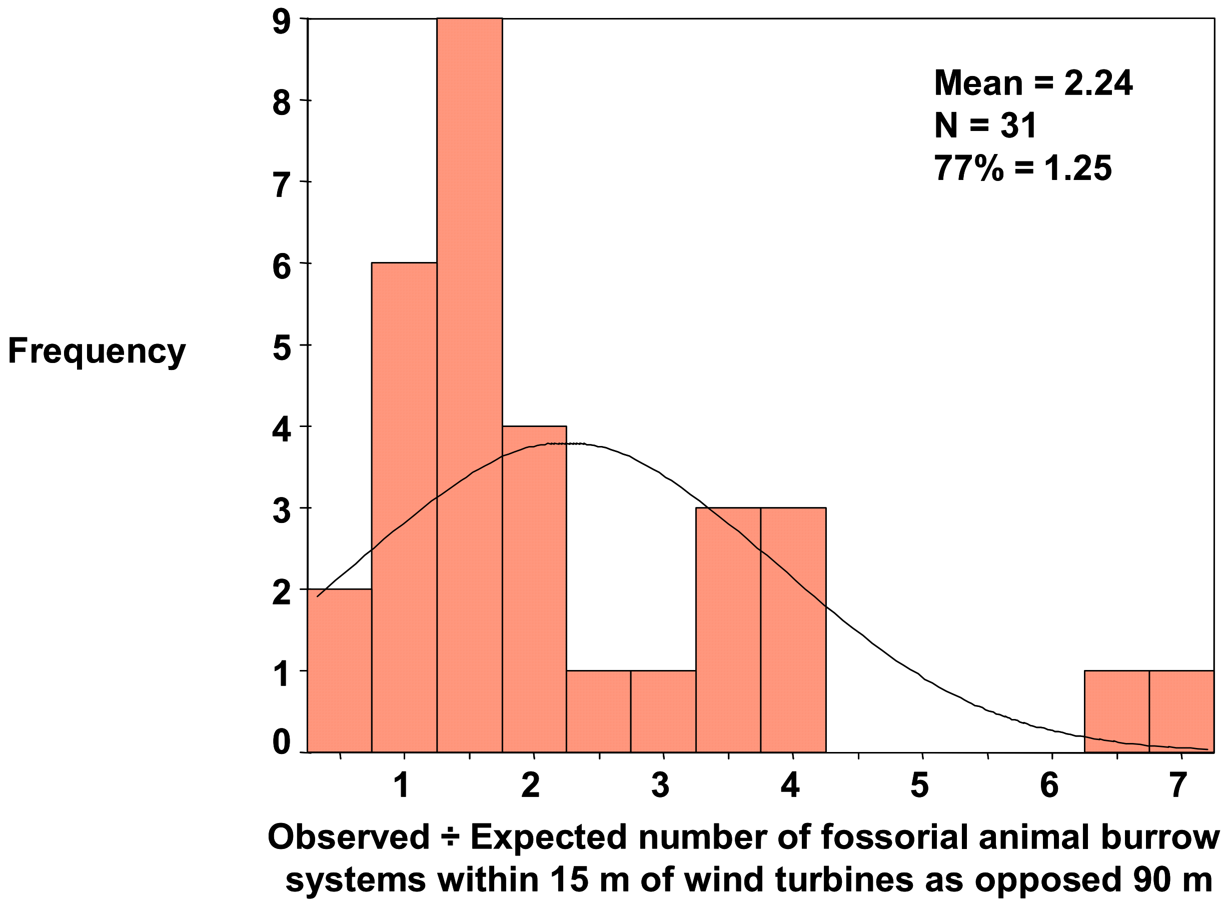


Figure 6-9. Frequency distribution of the degree of clustering of burrow systems of all fossorial mammals species around wind turbines

6.3.2 Seasonal and Inter-annual Variation in Distribution and Abundance

Eleven strings of wind turbines were selected for seasonal monitoring purposes, ten of which were on lands where rodenticide was applied in moderate intensity and one of which was on property where rodenticide was applied intensively. These wind turbine strings were grouped into eight groups (Figure 6-10), and for each group the seasonal distributions of burrow systems are shown in Figures 6-12, 6-14, 6-16, 6-18, 6-20, 6-22, 6-24, and 6-26. Each of these Figures is preceded by photographic representations of the conditions at the monitoring site (Figures 6-11, 6-13, 6-15, 6-17, 6-19, 6-21, 6-23, and 6-25).

The observed-to-expected ratio of pocket gopher burrow systems within 15 m of wind turbines differed significantly by season (ANOVA $F = 6.83$; $df = 3, 42$; $P < 0.001$). According to post-hoc LSD tests, this ratio was significantly less during winter, when it averaged slightly greater than zero (Figure 6-27A). Pocket gopher clustering at wind turbines did not differ significantly between spring, summer, and fall.

The observed-to-expected ratio of ground squirrel burrow systems within 15 m of wind turbines also differed significantly by season (ANOVA $F = 4.57$; $df = 3, 42$; $P < 0.010$). According to post-hoc LSD tests, this ratio was significantly greater during summer when it averaged 0.90 (Figure 6-27B). Ground squirrel avoidance of wind turbines did not differ significantly between winter, spring, and fall. Ground squirrels appeared to avoid locating burrow systems within 15 m of turbines during all seasons.

The density of pocket gopher burrow systems out to 90 m from wind turbines did not differ significantly among dates between summer 1999 and fall 2001 (ANOVA $F = 2.00$; $df = 4, 41$; $P = 0.114$). However, during this time period the density of ground squirrel burrow systems out to 90 m from wind turbines increased by 0.687 burrow systems per hectare (ha) per season (linear regression, ANOVA $F = 6.74$; $df = 1, 41$; $P < 0.050$). Figure 6-28 illustrates the difference in trends between pocket gopher and ground squirrel burrow system density out to 90 m from wind turbines.

6.3.3 Associations with Wind Turbine String Attributes and Range Management

The degree of clustering of pocket gophers within 15 m of wind turbines tended to differ significantly based on the intensity of rodent control implemented in the area (ANOVA $F = 2.88$; $df = 2, 30$; $P = 0.073$) (Figure 6-29). Based on post-hoc LSD tests, it was significantly less ($P = 0.048$) on areas without rodent control ($\bar{x} = 1.07$) compared to intermittent control ($\bar{x} = 3.67$).

In the rodent control areas, pocket gopher clustering at wind turbines varied significantly by slope aspect (ANOVA $F = 5.64$; $df = 5, 53$; $P < 0.001$), with the greatest degrees of clustering on west and southwest-facing slopes, followed by northwest-facing slopes (Table 6-1). Pocket gopher clustering at wind turbines did not vary significantly by slope aspect in the areas where rodents were not controlled (ANOVA $F = 0.62$; $df = 3, 14$; $P = 0.620$).

Figure 6-10. Locations of groups of wind turbines monitored for burrow system distributions by season during 2001 and 2002 Numbers correspond with the eight monitoring groups of turbines.

A

B

Figure 6-11. Wind turbine monitoring Group 1 viewed from the south (A) and from the northern aspect of the wind turbines toward the south (B)

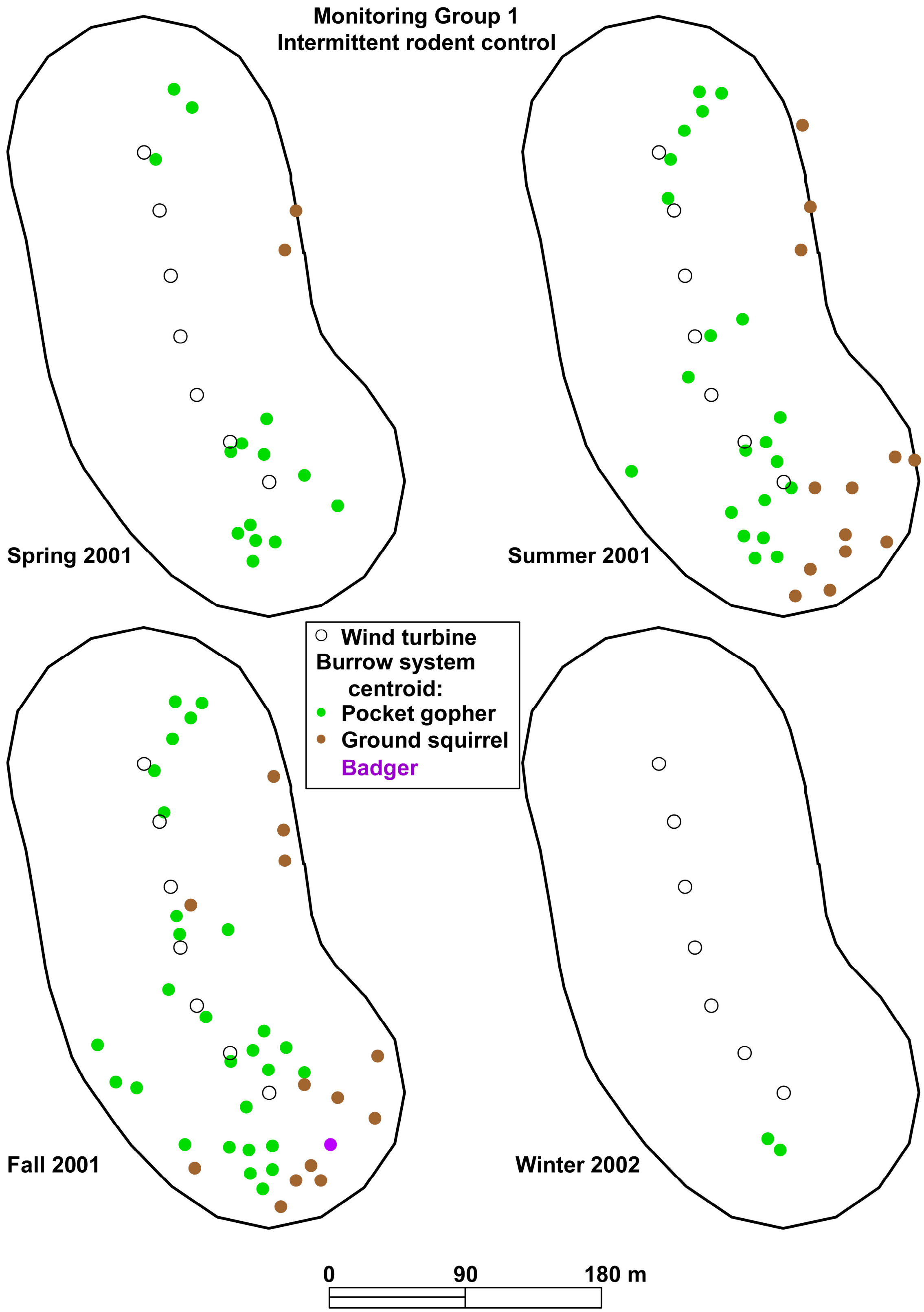


Figure 6-12. Seasonal distribution of burrow systems around wind turbine monitoring Group 1

Figure 6-13. Wind turbine monitoring Group 2 viewed from its southern aspect

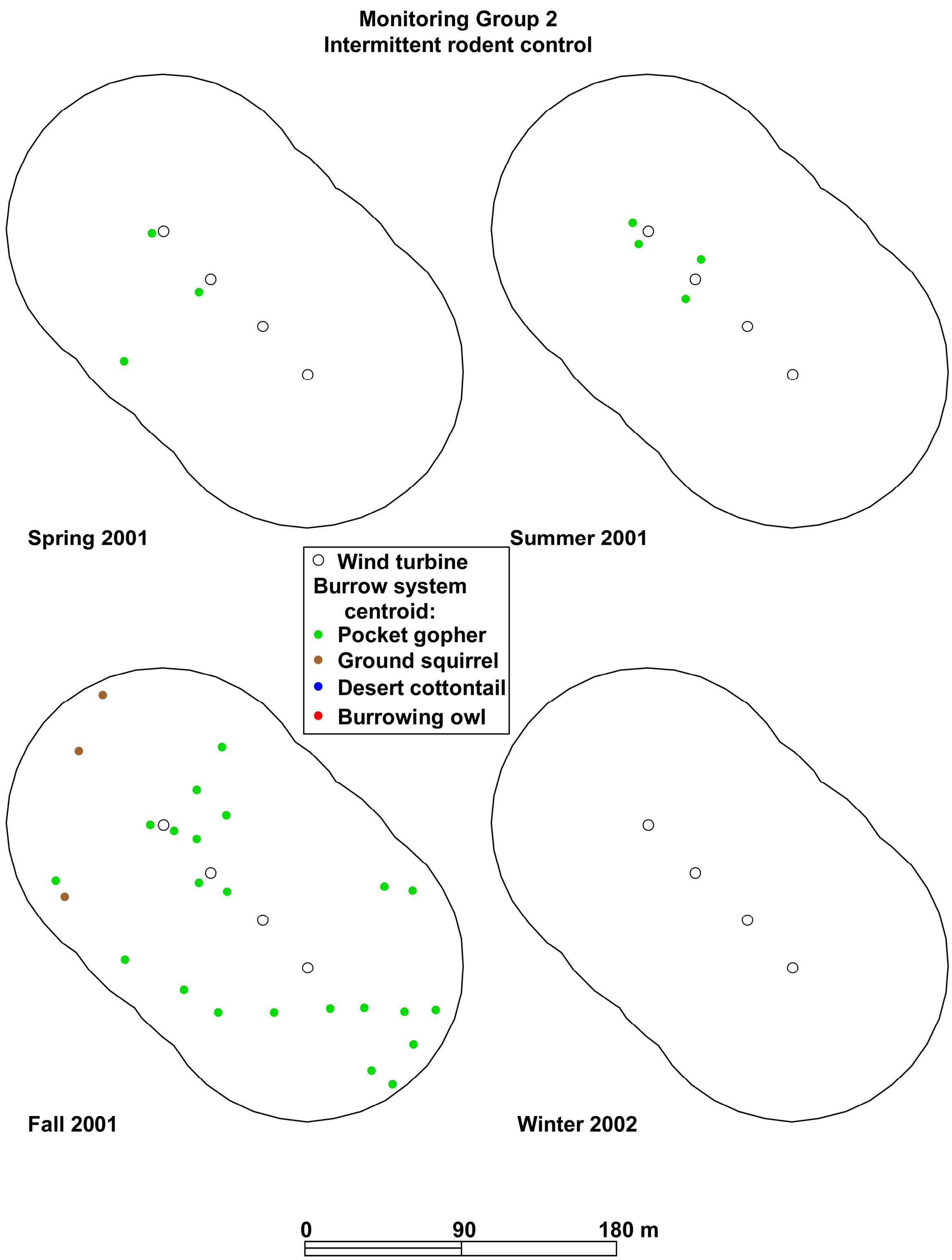


Figure 6-14. Seasonal distribution of burrow systems around wind turbine monitoring Group 2

Figure 6-15. Wind turbine monitoring Group 3 viewed from the north

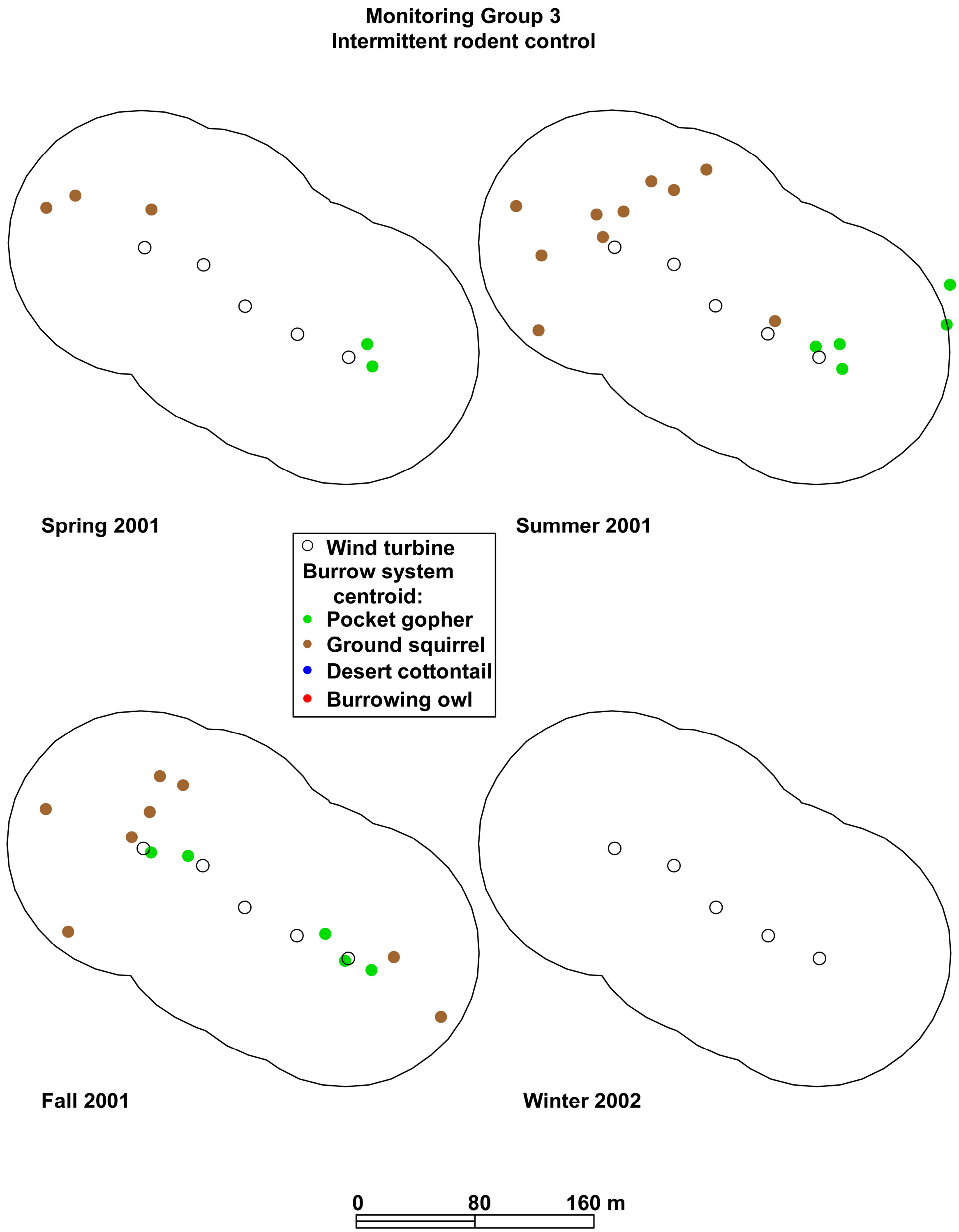


Figure 6-16. Seasonal distribution of burrow systems around wind turbine monitoring Group 3

Figure 6-17. Wind turbine monitoring Group 4 viewed north from the southern aspect of the wind turbines

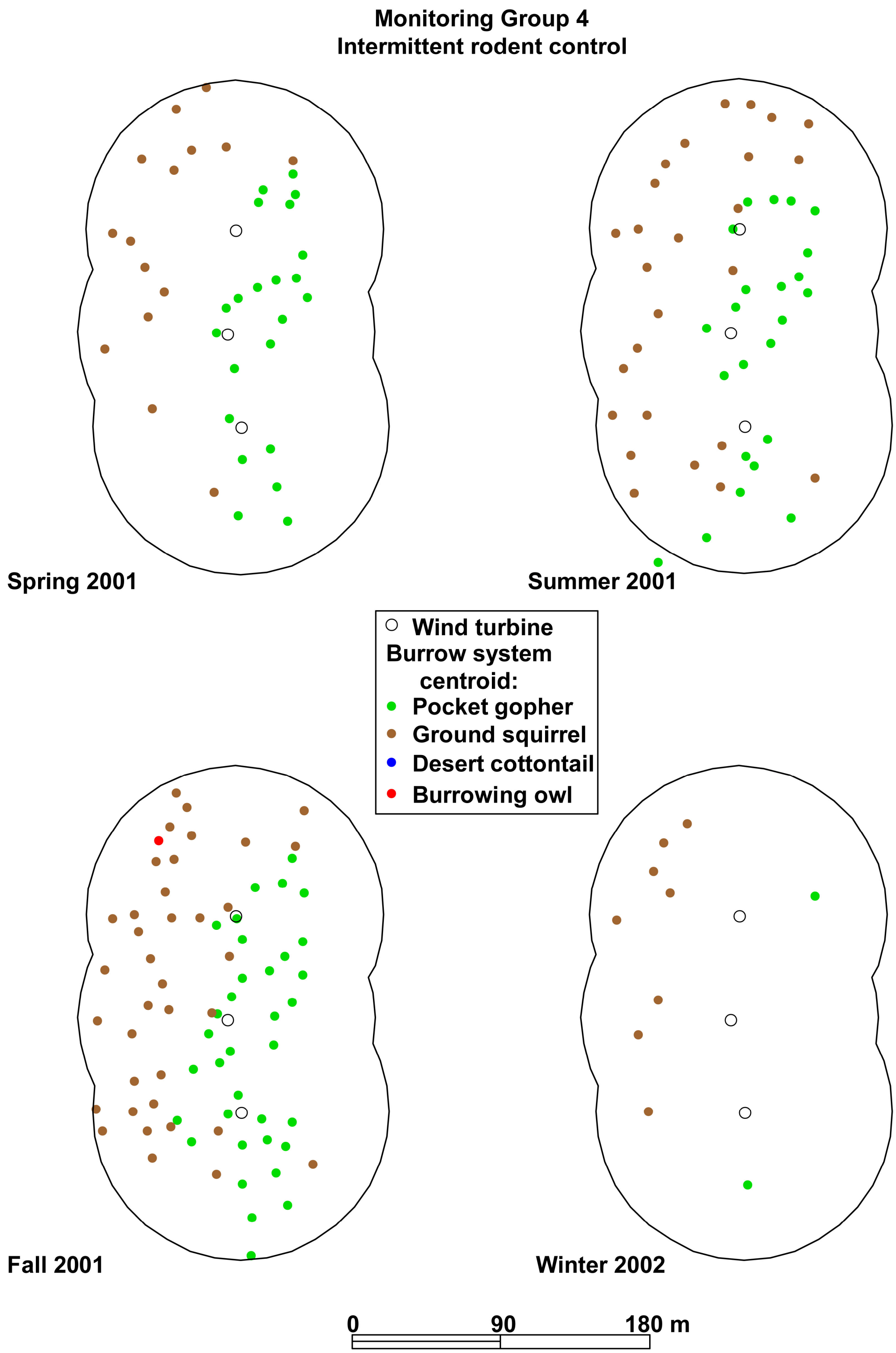


Figure 6-18. Seasonal distribution of burrow systems around wind turbine monitoring Group 4

Figure 6-19. Wind turbine monitoring Group 5 viewed north from the southern aspect of the wind turbines

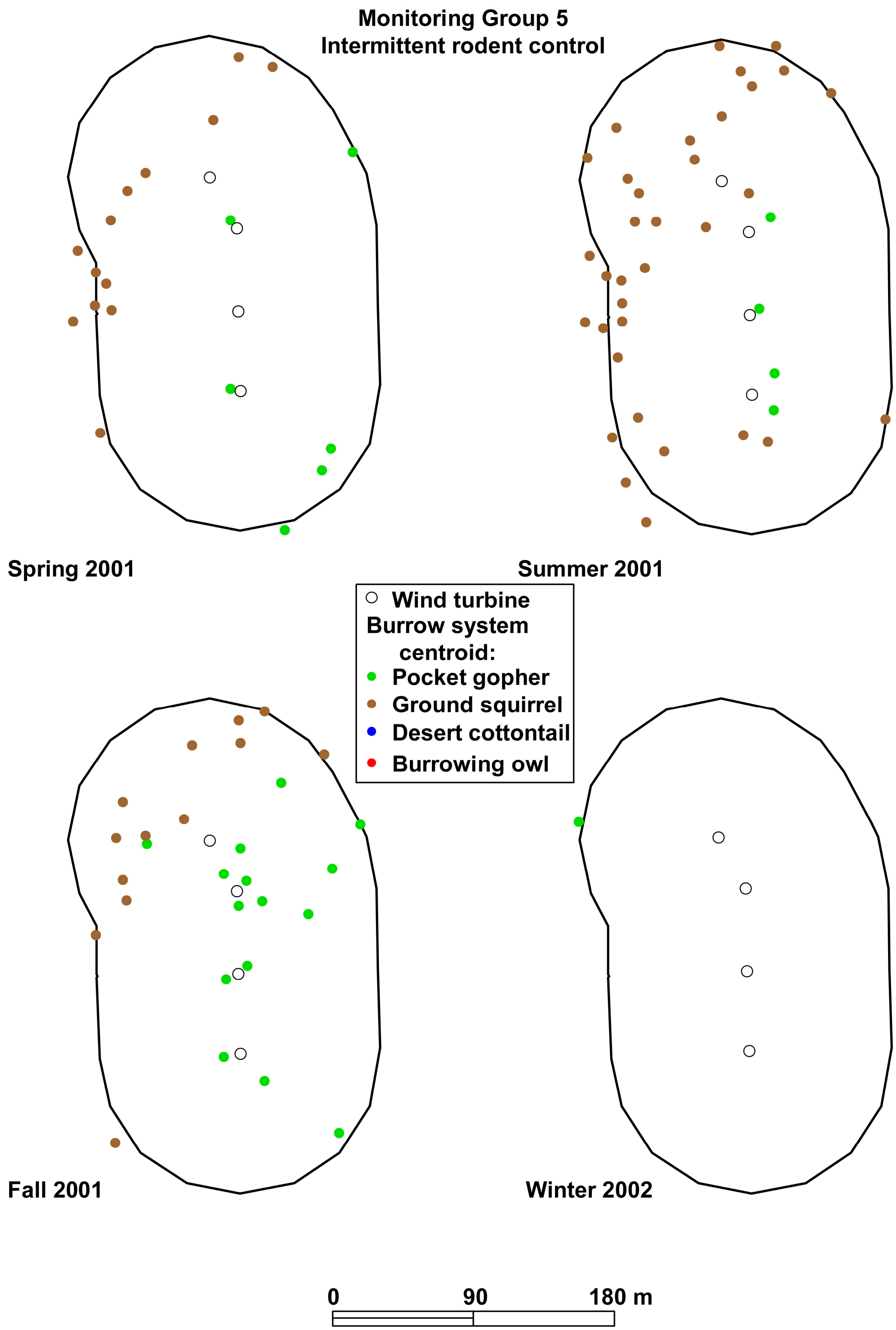


Figure 6-20. Seasonal distribution of burrow systems around wind turbine monitoring Group 5

A

B

Figure 6-21. Wind turbine monitoring Group 6 viewed south from the middle of the eastern row (A) and north from the middle of the western row (B)

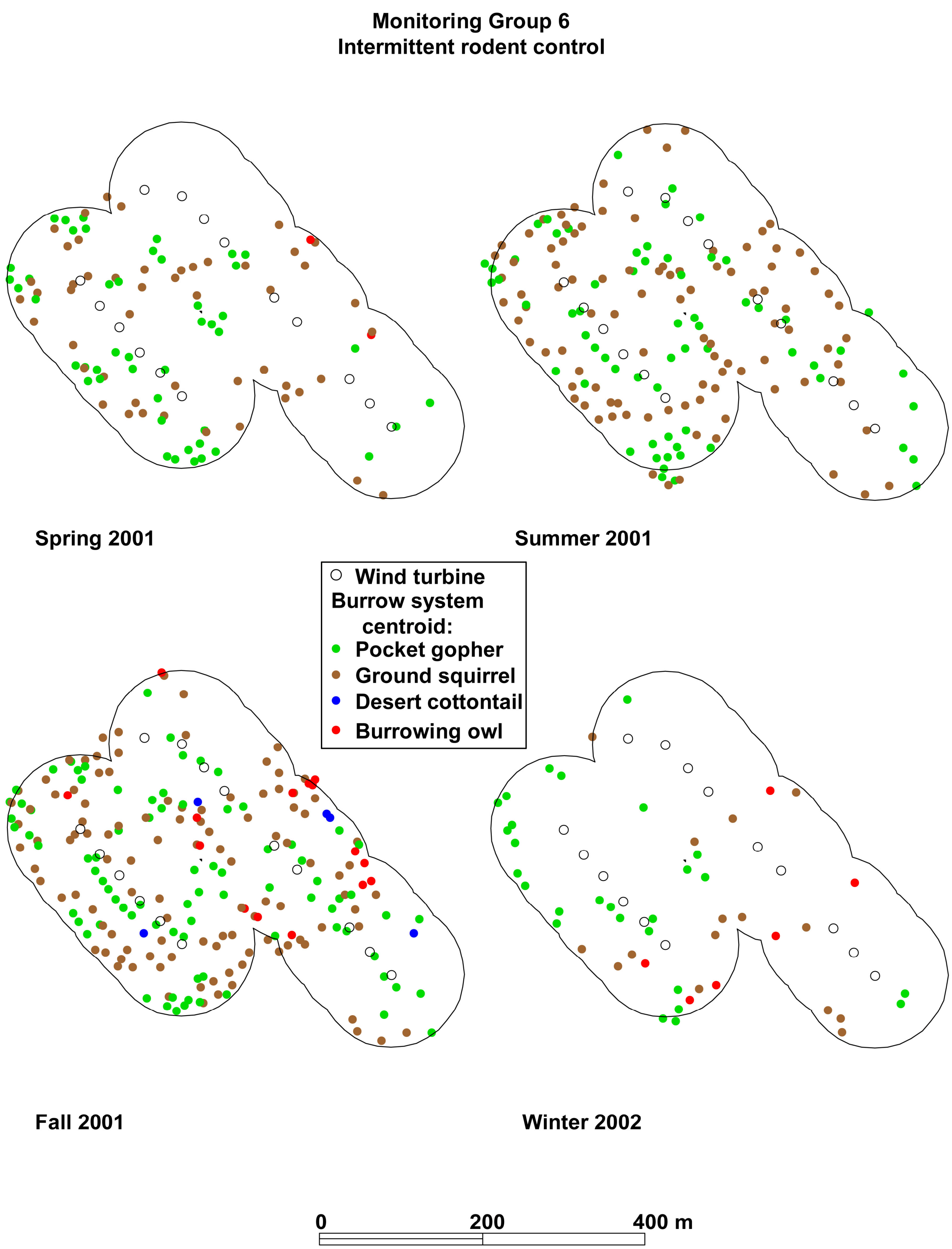


Figure 6-22. Seasonal distribution of burrow systems around wind turbine monitoring Group 6

Figure 6-23. Wind turbine monitoring Group 7 viewed north from the southern aspect of the wind turbines

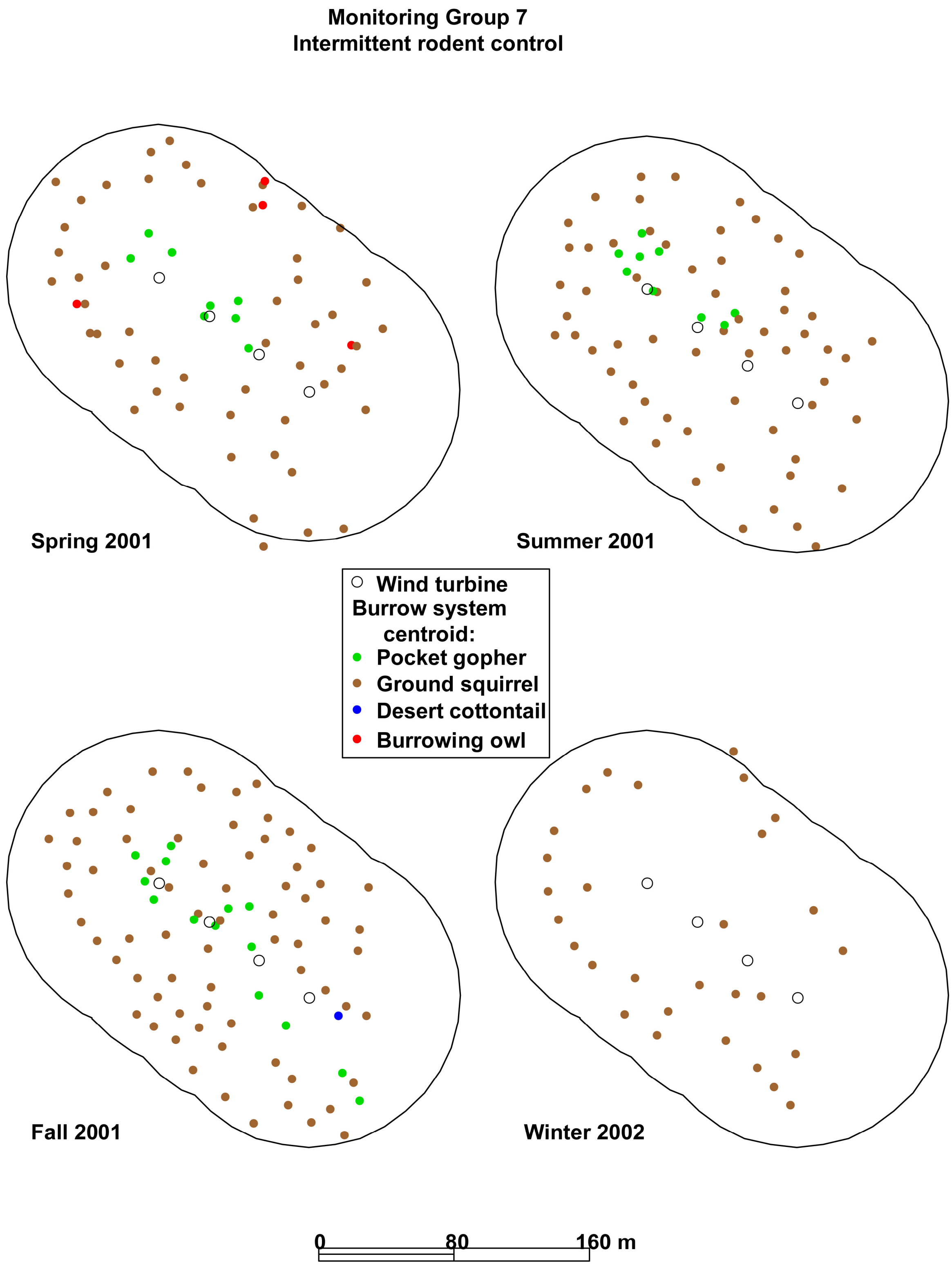


Figure 6-24. Seasonal distribution of burrow systems around wind turbine monitoring Group 7

A

B

Figure 6-25. Wind turbine monitoring Group 8 viewed south from the middle of the row (A) and north from the middle of the row (B). The large wind turbines in the foreground of photo B were non-operational throughout our study.

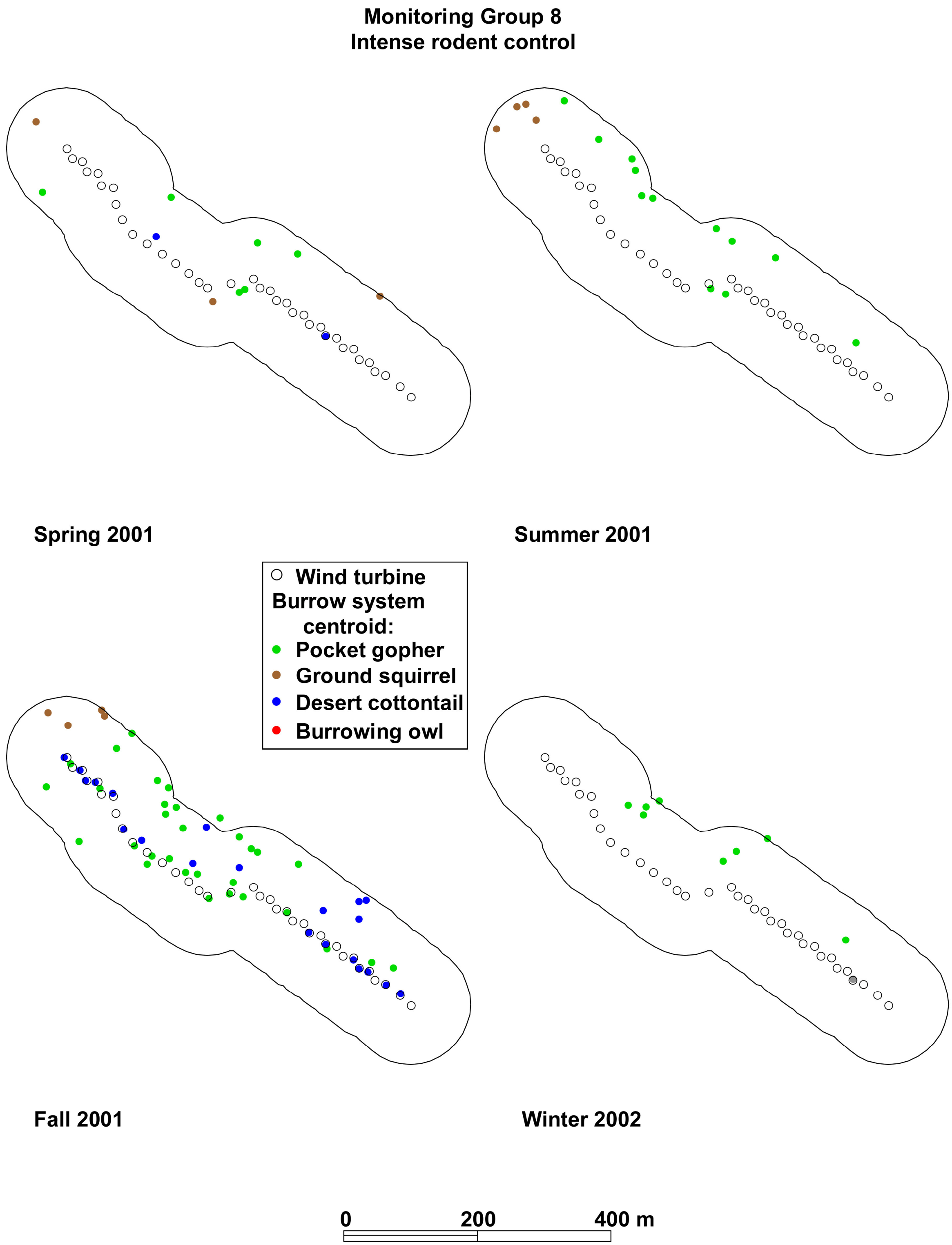


Figure 6-26. Seasonal distribution of burrow systems around wind turbine monitoring Group 8

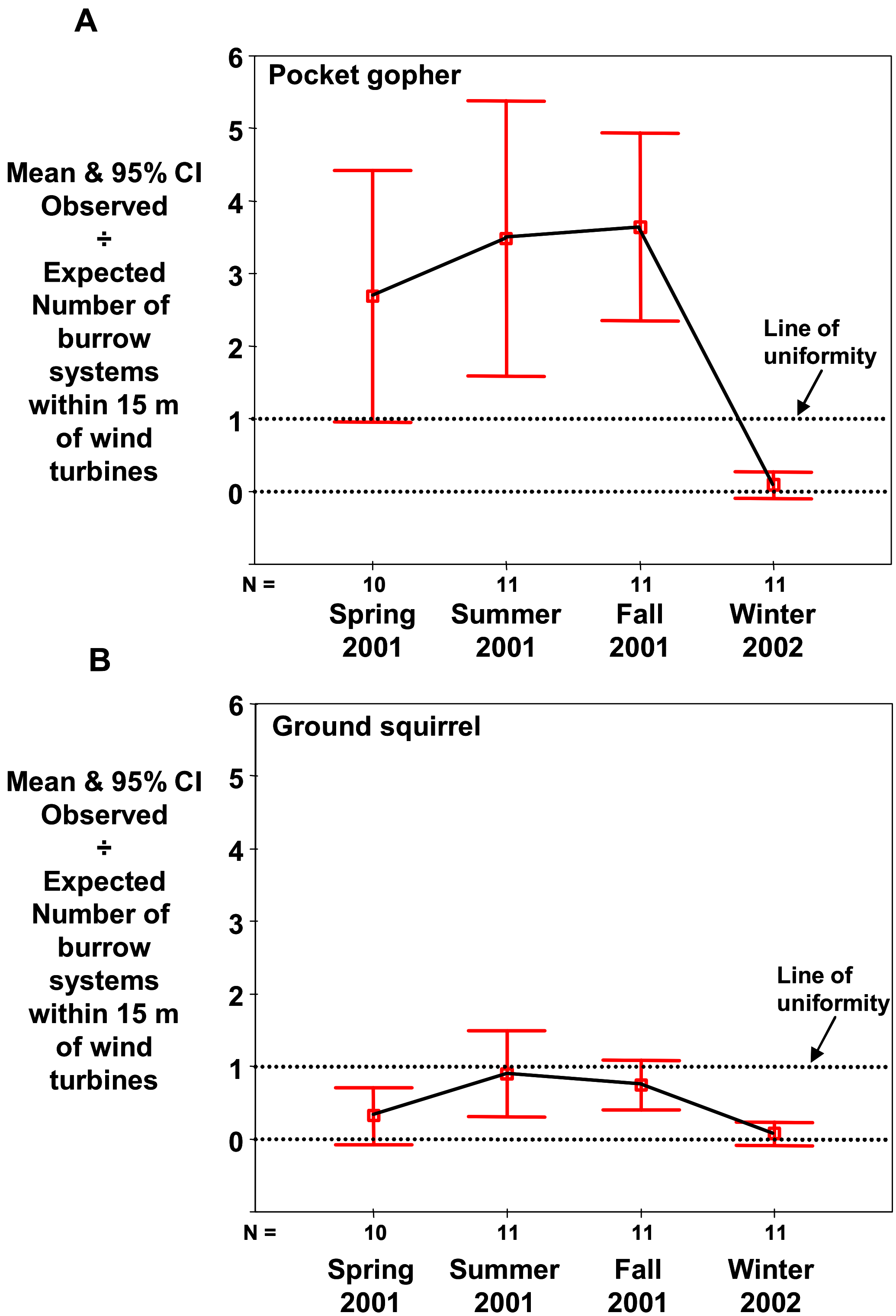


Figure 6-27. Seasonal pattern of the degree of clustering of burrow systems at wind turbines for (A) pocket gopher and (B) ground squirrel

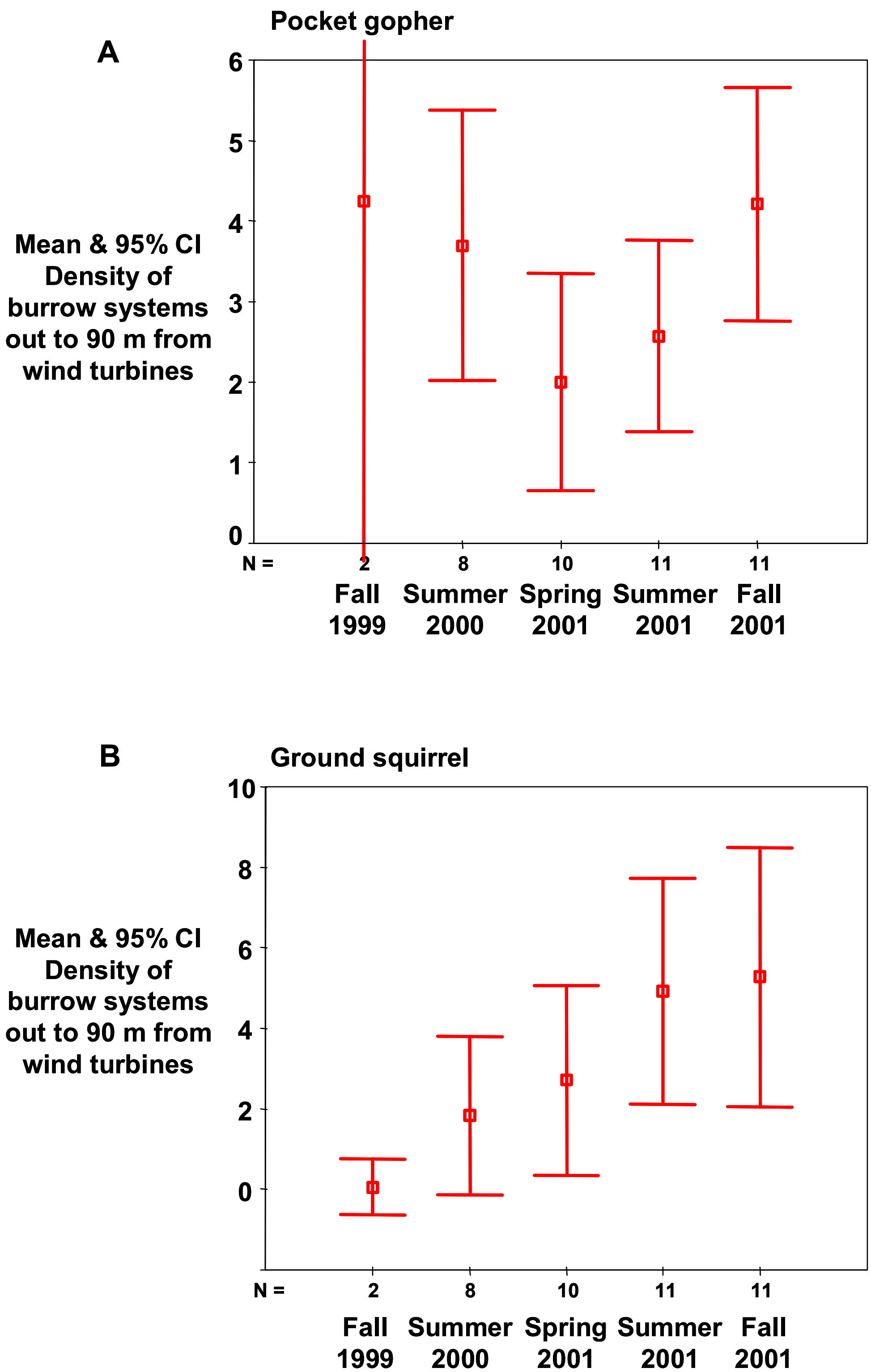


Figure 6-28. Trends through the study in density of burrow systems out to 90 m from wind turbines for (A) pocket gophers and (B) ground squirrels

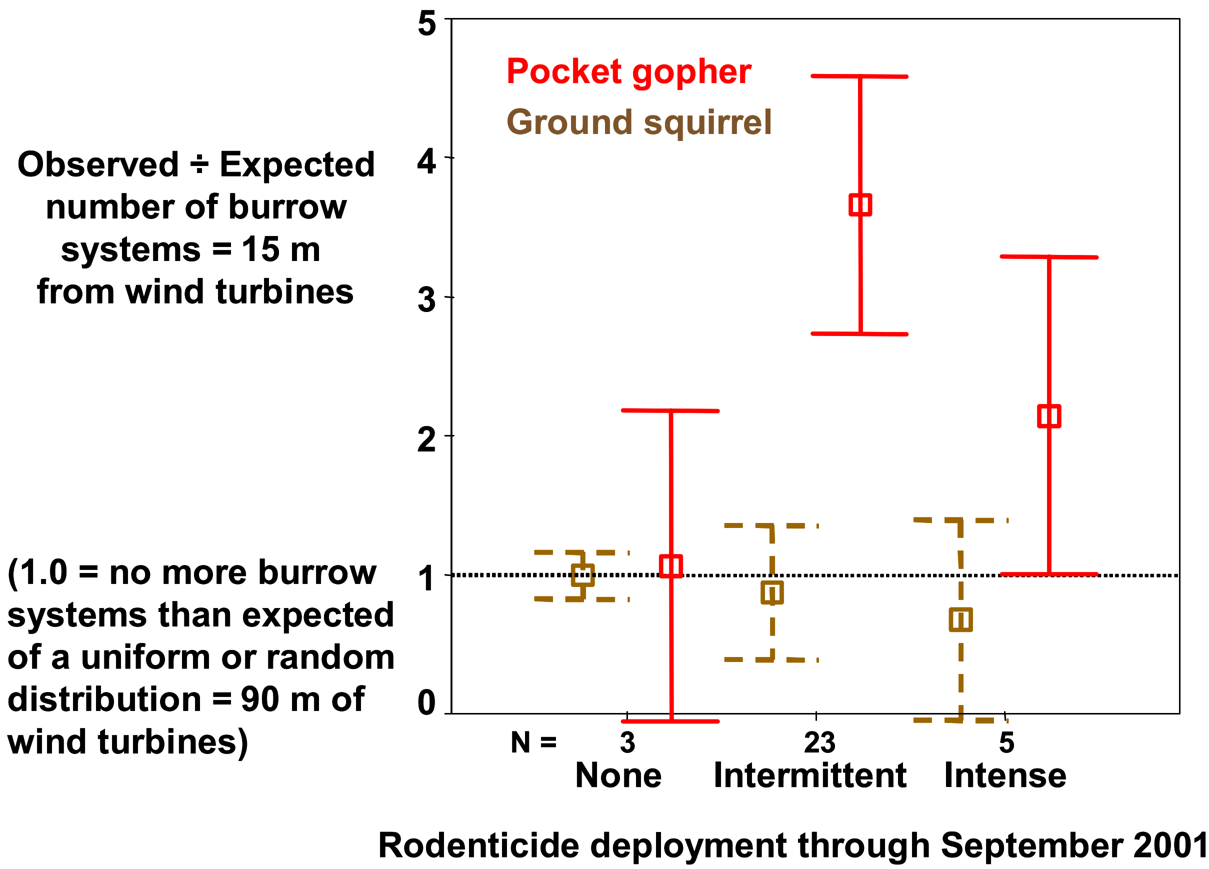


Figure 6-29. Relationship between degree of clustering of pocket gopher and ground squirrel burrow systems around wind turbines and the intensity of rodent control applied in the area

The degree of pocket gopher clustering at wind turbines did not vary significantly with physical relief, where relief was categorized as plateaus, slopes, and ridges (ANOVA $F = 0.74$; $df = 2, 68$; $P = 0.479$). It also did not vary significantly with relief within the areas of rodent control (ANOVA $F = 0.07$; $df = 2, 53$; $P = 0.929$). It correlated positively with the average change in elevation per wind turbine in the string of wind turbines ($r_p = 0.27$, $n = 69$, $P < 0.05$), and with the percentage of the string in a canyon ($r_p = 0.36$, $n = 69$, $P < 0.001$). It did not correlate significantly with the average edge index in the string. It correlated positively with the average number of cattle pats per wind turbine along the turbine string ($r_p = 0.51$, $n = 69$, $P < 0.001$) and 20–40 m away ($r_p = 0.49$, $n = 69$, $P < 0.001$), but negatively with the index of the abundance of cottontail fecal pellets along the turbine string ($r_p = -0.32$, $n = 69$, $P < 0.001$) and 20–40 m away ($r_p = -0.32$, $n = 69$, $P < 0.001$).

Table 6-1. Mean comparison (ANOVA) of observed ÷ expected number of gopher burrow systems in areas treated with rodenticide

Aspect	N	Mean	SD	LSD test, P < 0.05
Flat	10	2.48	2.04	
Over hill or ridge	10	3.44	1.88	
East, Northeast	12	1.60	1.40	
Southeast, South	6	3.82	2.10	
Southwest, West	2	10.27	9.87	> all other aspects
Northwest, North	14	4.27	1.97	>East Northeast

Ground squirrel burrows did not cluster at wind turbines to the degree that pocket gopher burrow systems did, and they did not differ significantly according to intensity of rodent control (ANOVA $F = 0.10$; df = 2, 30; $P = 0.905$) (Figure 6-29). Ground squirrels did not cluster around the wind turbines (Figures 6-8A and 6-12), which means they did not cluster around the access roads and cuts into the hillsides made for wind turbine laydown areas.

The degree of ground squirrel clustering at wind turbines correlated inversely with increasing elevation ($r_p = -0.32$, $n = 69$, $P < 0.001$). It correlated positively with the mean number of cattle pats per wind turbine along the string of wind turbines ($r_p = 0.34$, $n = 69$, $P < 0.001$). Increased rodent control intensity appeared to increase the variation in the degree of ground squirrel clustering at wind turbines (Figure 6-29).

Alternatively, the degree of clustering of desert cottontail burrows at wind turbines was greater than it was for ground squirrels, and it differed significantly according to level of rodent control intensity (ANOVA $F = 4.175$; df = 2, 30; $P = 0.026$) (Figure 6-30). Based on post-hoc LSD tests, it tended to be greater ($P = 0.054$) in areas lacking rodent control ($\bar{x} = 4.82$) compared to those with intermittent control ($\bar{x} = 1.29$), and significantly greater in areas of intense control ($\bar{x} = 4.59$) compared to intermittent control.

The degree of clustering of all fossorial animal burrows at wind turbines did not differ significantly according to level of rodent control intensity (ANOVA $F = 0.847$, df = 2, 30, $P = 0.439$) (Figure 6-31). No burrowing owl burrows were found within 15 m of wind turbines, so this species displayed no clustering at wind turbines and no variation in clustering according to rodent control intensity.

The density of pocket gopher burrow systems within 15 m of wind turbines differed significantly among areas of different intensities of rodent control (ANOVA $F = 4.71$; df = 2, 31; $P < 0.05$). Pairwise LSD post-hoc tests indicated pocket gopher density within 15 m of wind turbines was significantly greater in the areas of intermittent rodent control ($\bar{x} = 11.9$ burrows/ha) than in the areas of no control ($\bar{x} = 0.9$ burrows/ha) and intense control ($\bar{x} = 4.0$ burrows/ha) (Figure 6-32A).

The density of pocket gopher burrow systems out to 90 m of wind turbines tended to differ between levels of rodent control (ANOVA $F = 2.52$; df = 2, 31; $P < 0.10$). Pairwise LSD post-hoc tests indicated it tended to be greater in the areas of intermittent control ($\bar{x} = 3.6$ burrows/ha) than in areas of no control ($\bar{x} = 1.5$ burrows/ha) (Figure 6-32B). Pocket gopher density in the intermittently controlled area was more than twice that found on the areas with no rodent control, and within 15 m of wind turbines it was twelve times greater. Gopher burrow system density adjusted by the mean per rodent control intensity did not relate significantly to any other variables we measured on physiographic conditions or types of wind turbine.

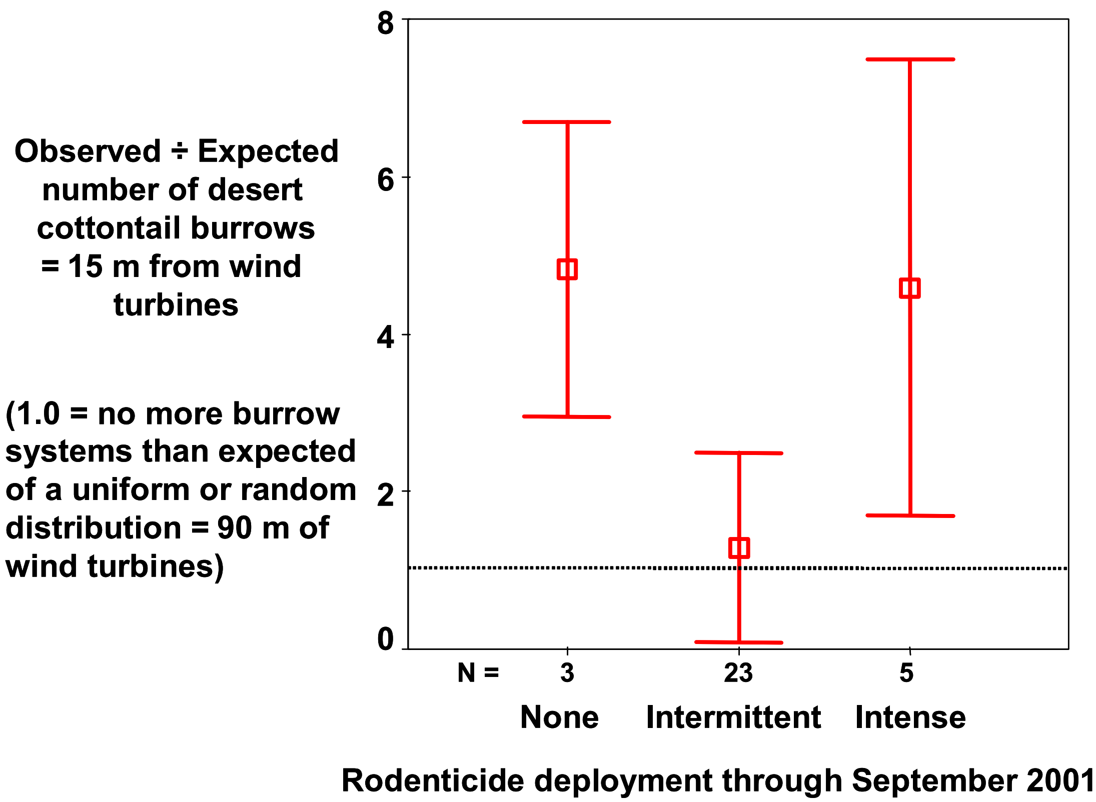


Figure 6-30. Relationship between degree of clustering of desert cottontail burrow systems around wind turbines and the intensity of rodent control applied in the area

The density of ground squirrel burrow systems within 15 m of wind turbines tended to differ between areas by rodent control intensity (ANOVA $F = 2.59$; $df = 2, 31$; $P < 0.10$). Pairwise LSD post-hoc tests indicated ground squirrel burrow system density within 15 m of the turbine was greatest where rodenticide was not deployed ($\bar{x} = 9.7$) and least where rodenticide was most intensely deployed ($\bar{x} = 1.0$) (Figure 6-32A).

The density of ground squirrel burrow systems within 90 m of wind turbines differed significantly among areas of different rodent control intensity (ANOVA $F = 3.38$; $df = 2, 31$; $P < 0.05$). Pairwise LSD post-hoc tests indicated ground squirrel burrow system density within 90 m was greatest where rodenticide was not deployed ($\bar{x} = 10.0$) and least where rodenticide was most intensely deployed ($\bar{x} = 1.5$) (Figure 6-32B).

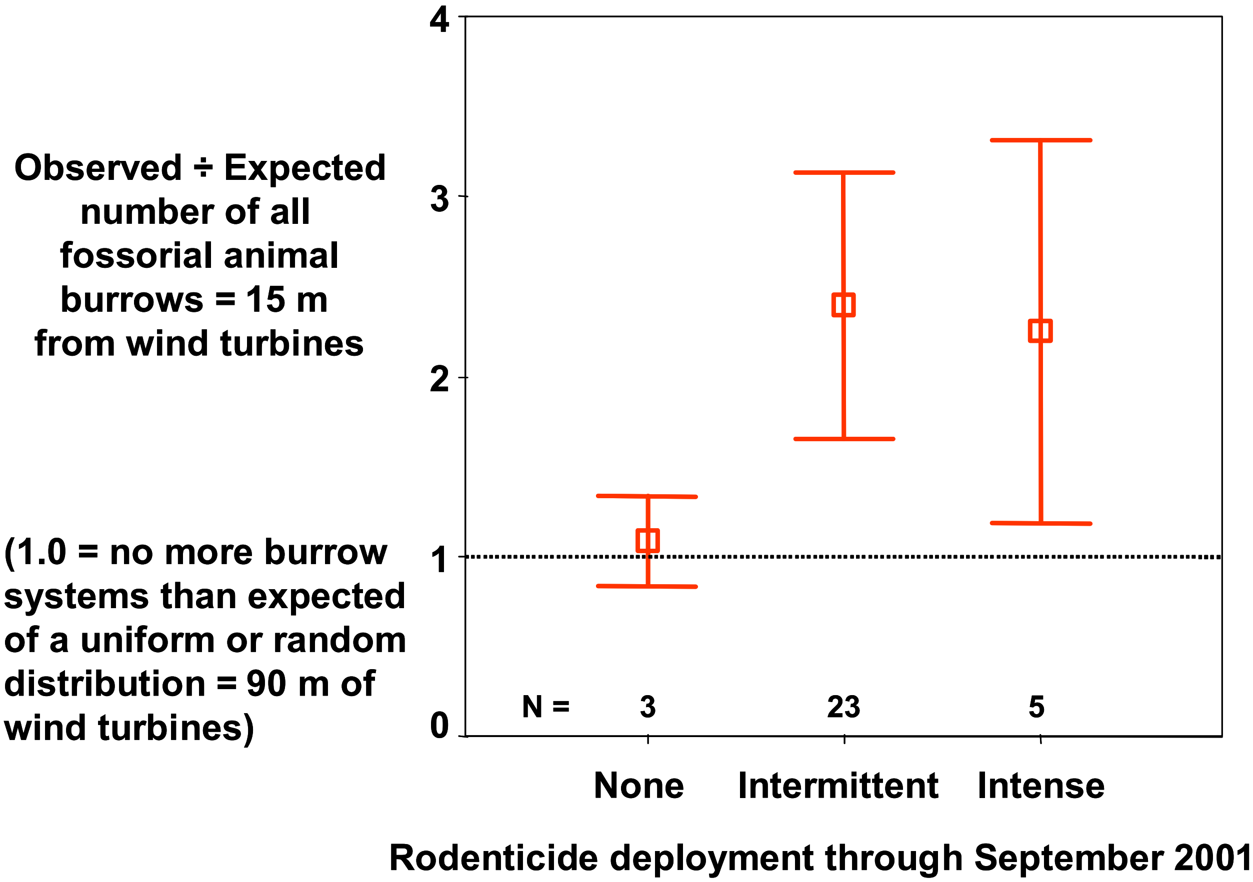


Figure 6-31. Relationship between degree of clustering of burrow systems of all fossorial mammal species around wind turbines and the intensity of rodent control applied in the area

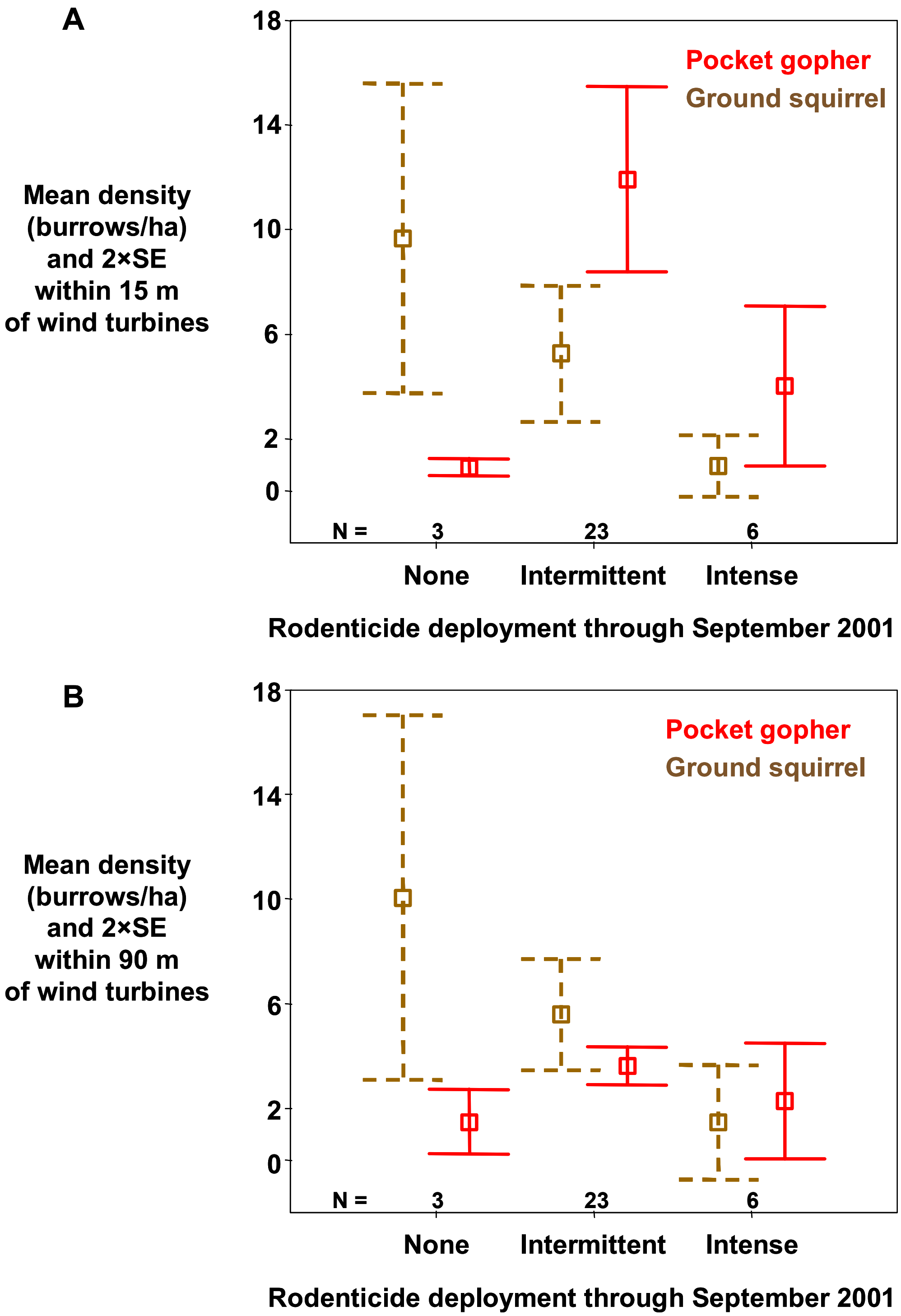


Figure 6-32. Relationship between mean density of pocket gopher and ground squirrel burrow systems within 15 m (A) and 90 m (B) of wind turbines and the intensity of rodent control applied in the area

Ground squirrel burrow system density in the intense rodent control areas averaged only 14% of the average density where no rodent control was implemented. Ground squirrel burrow system density adjusted by the mean per rodent control intensity did not relate significantly to any other variables we measured on physiographic conditions or turbine types.

Neither within 15 m or 90 m did the density of desert cottontail burrows differ significantly among levels of rodent control intensity.

The density of burrow systems of all species studied varied significantly by intensity of rodent control (ANOVA $F = 3.65$; $df = 2, 31$; $P < 0.05$), and post-hoc LSD tests suggested areas of intermittent control maintained higher densities of all fossorial animal species burrows ($\bar{x} = 9.6$) than did areas of intense control ($\bar{x} = 4.1$) (Figure 6-33). The density of burrow systems of all species studied tended to differ by intensity of rodent control (ANOVA $F = 3.04$; $df = 2, 31$; $P < 0.10$). Post-hoc LSD tests suggested areas of intense control ($\bar{x} = 4.3$) were significantly less dense than areas of intermittent control ($\bar{x} = 9.5$) or no control ($\bar{x} = 11.8$).

6.3.4 Relationships Between Raptor Mortality and Small Mammal Burrow Distributions

Figures 6-34 through 6-44 illustrate animal burrow distributions around some groups of wind turbines, as examples. Figures 6-34 through 6-36 depict the distributions of burrow systems of fossorial animals in some of the areas receiving no rodent control through 2001. Figures 6-37 through 6-41 depict burrow distributions in some of the areas treated intermittently with rodent poison during the entire study period and prior to the study. Figures 6-42 through 6-44 depict burrow distributions in some of the areas subjected to intense rodent abatement efforts during and preceding our study. Estimates of mortality generated for those groups of wind turbines in the figures are provided as examples of how mortality related to abatement efforts and resulting distributions of raptor prey species.

In areas of no rodent control through 2001, raptor mortality decreased, with increasing density of ground squirrel burrow systems within 90 m of wind turbines (Figure 6-45). In areas of intermittent control, raptor mortality did not relate significantly to ground squirrel burrow density, but in areas of intense control it increased rapidly with increasing ground squirrel density out to 90 m (Figure 6-45). These patterns were driven most strongly by red-tailed hawk and burrowing owl mortality. They were also evident when raptor mortality was compared to the density of ground squirrel burrow systems within 15 m of wind turbines (Figure 6-46); however, the regression slope estimated for the intensely controlled areas was steeper within this distance domain than it was for the 90-m radius.

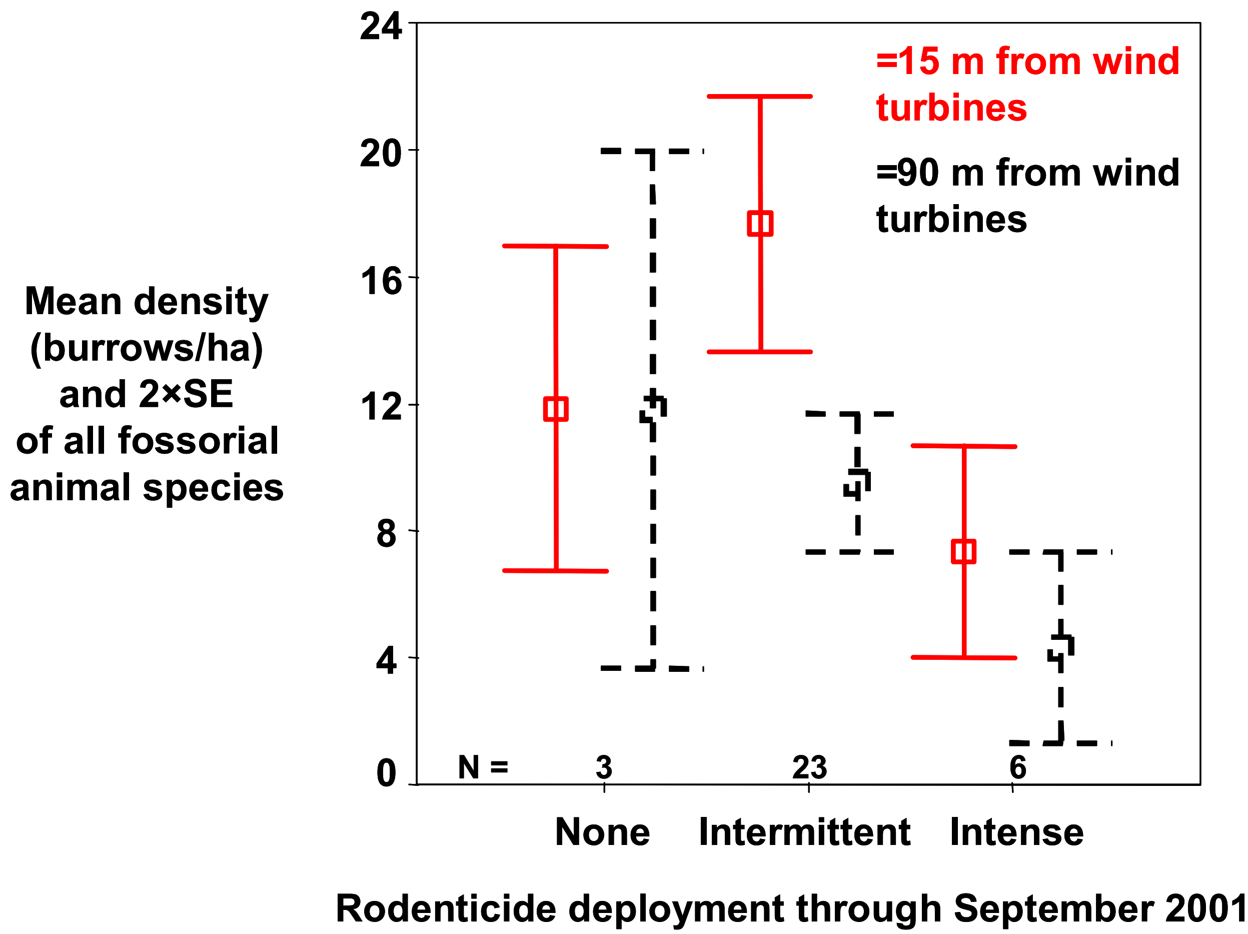


Figure 6-33. Relationship between mean density of burrow systems of all fossorial mammal species within 15 m and 90 m of wind turbines and the intensity of rodent control applied in the area

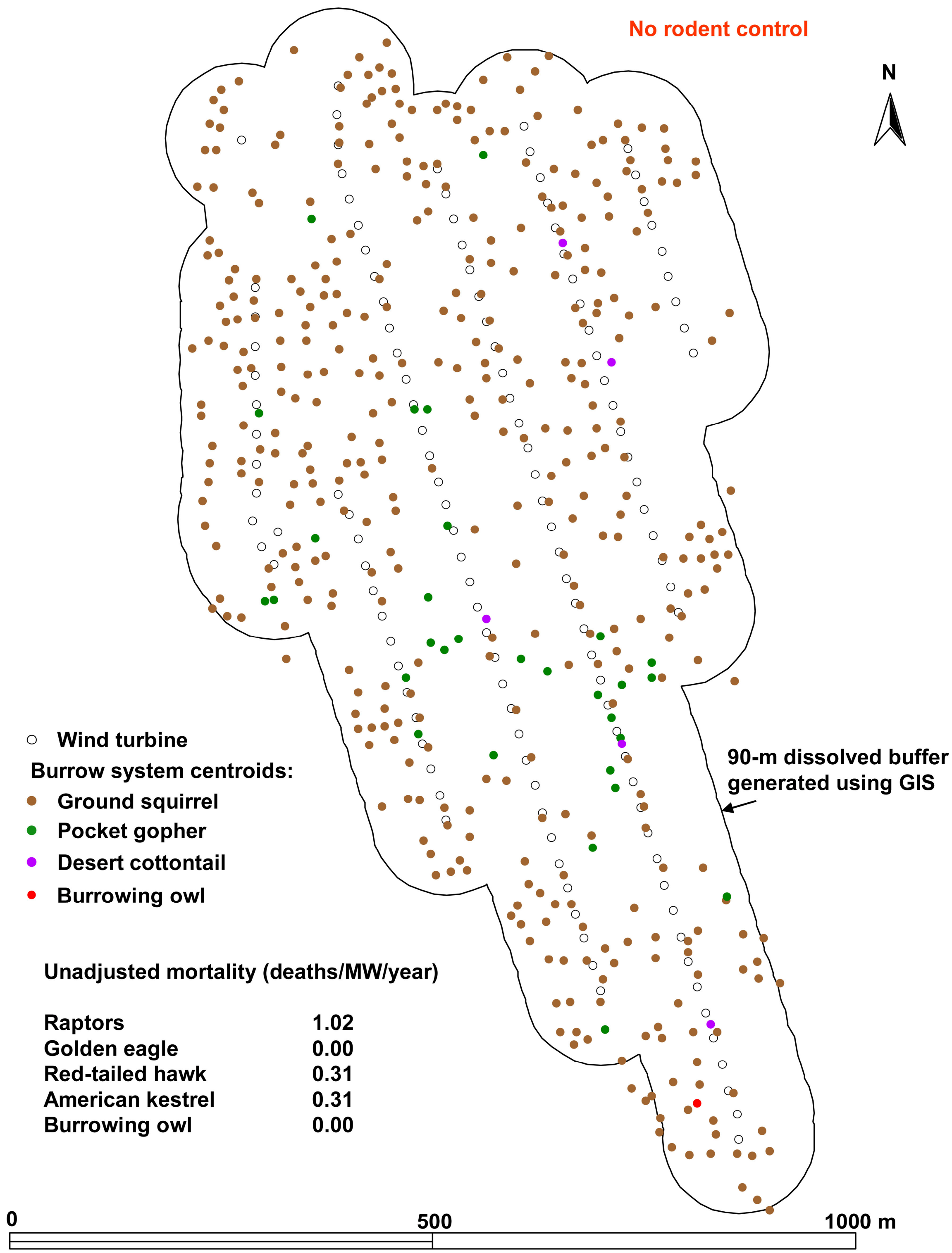


Figure 6-34. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in the Mountain House area where rodent control was not applied until 2002

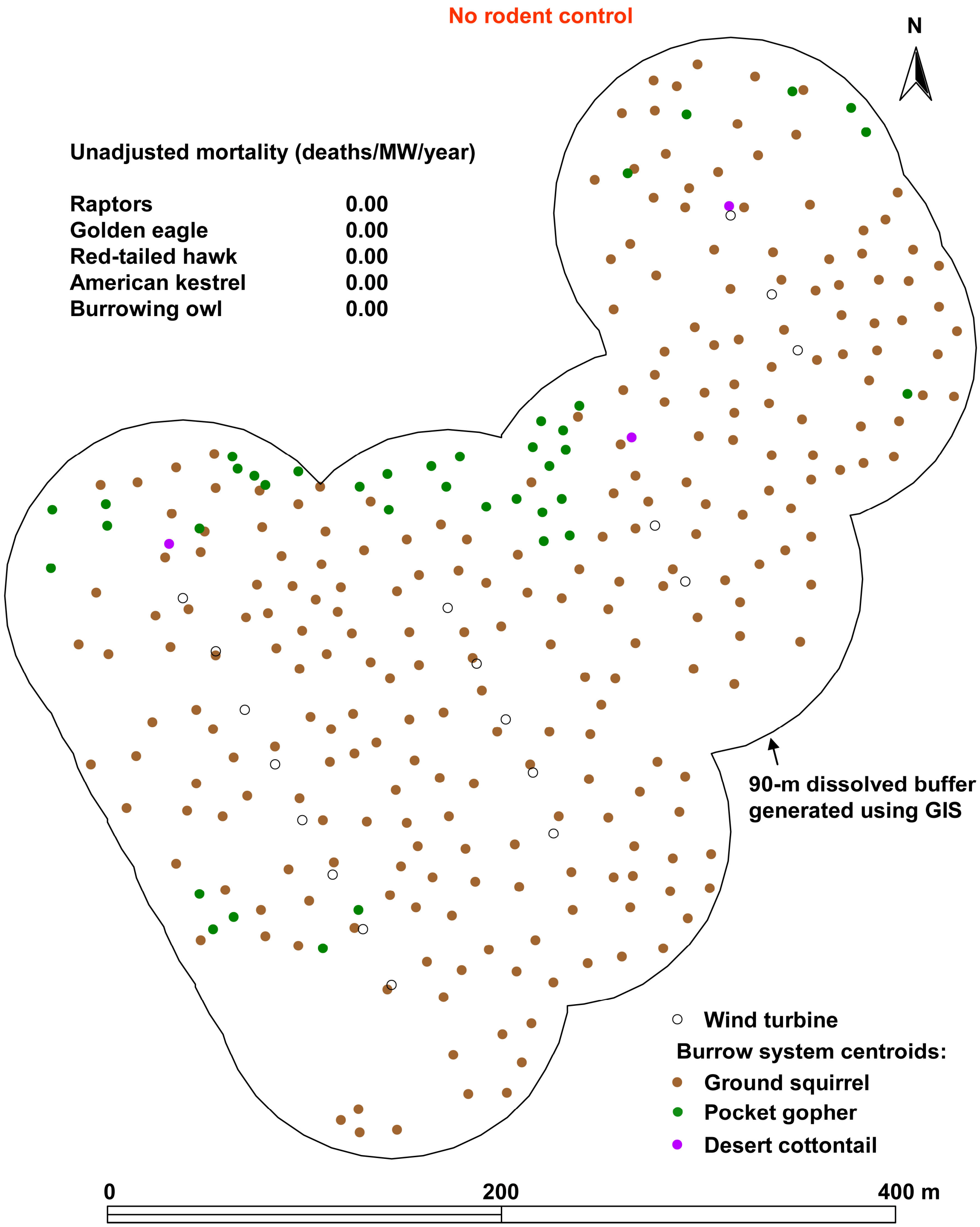


Figure 6-35. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in the Midway area where rodent control was not applied until 2002

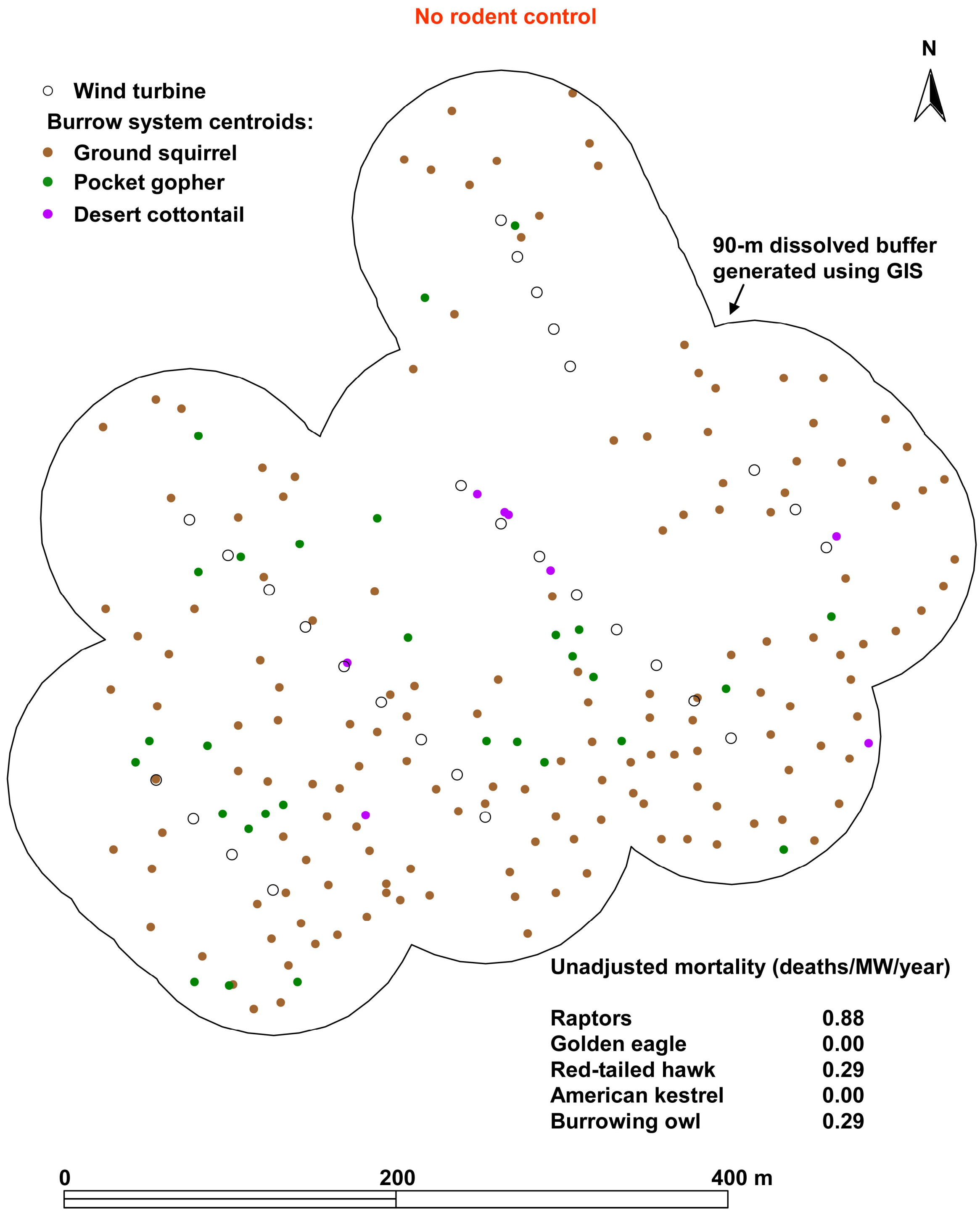


Figure 6-36. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in the east-central area of the APWRA and where rodent control was not applied until 2002

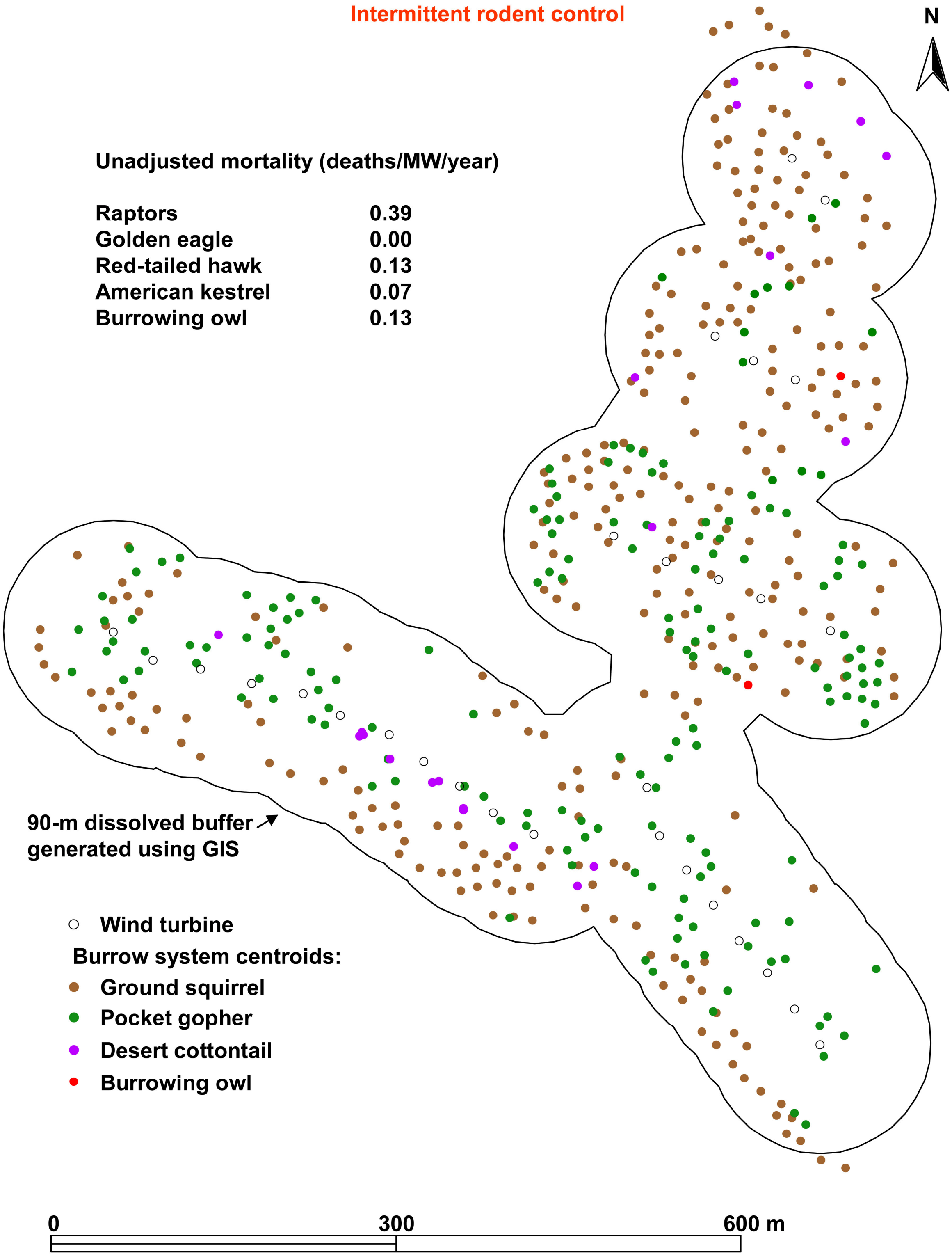


Figure 6-37. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in the central aspect of EnXco's turbines and where rodent control was applied intermittently

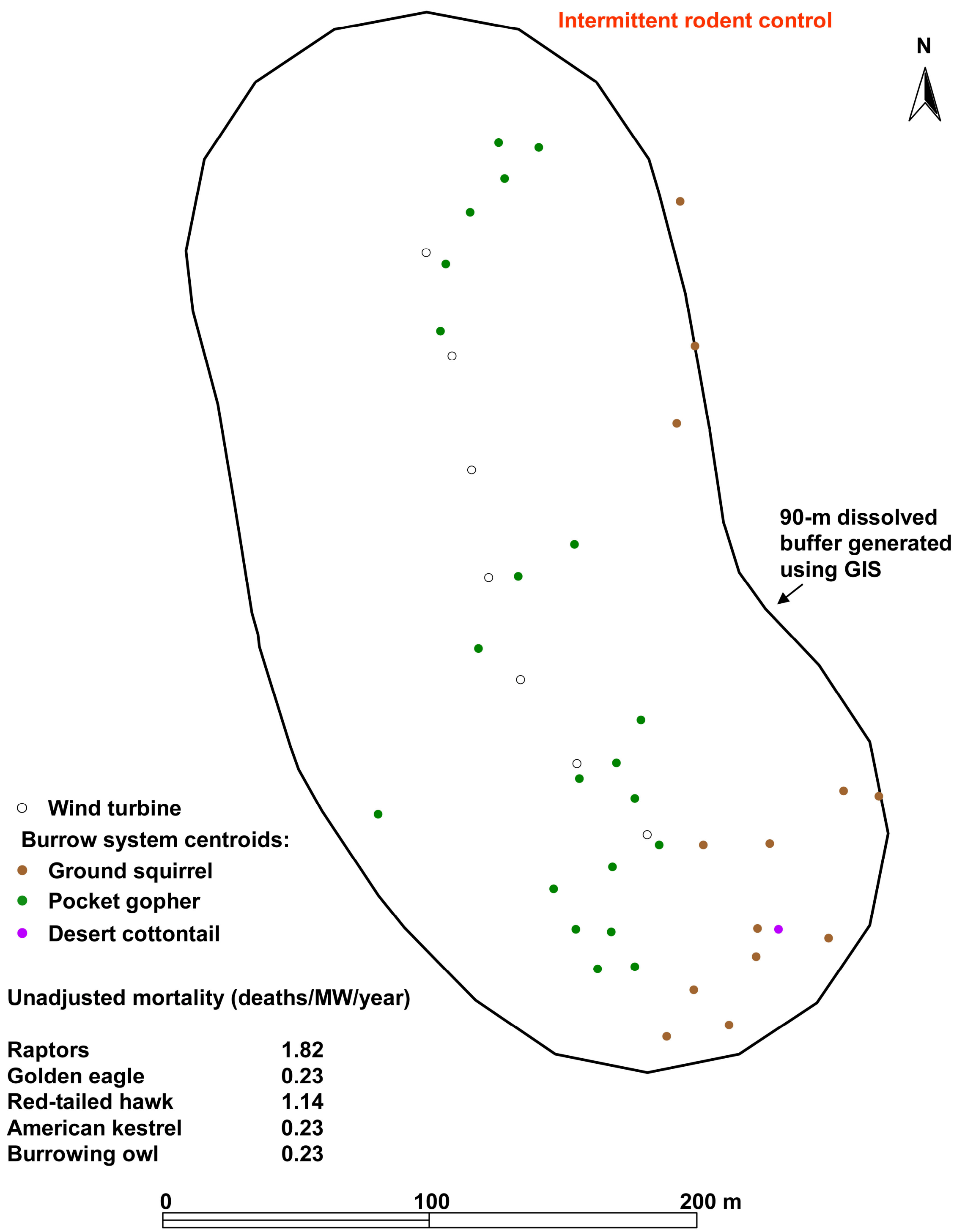


Figure 6-38. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines on the northern fringe of EnXco's turbine field and where rodent control was applied intermittently

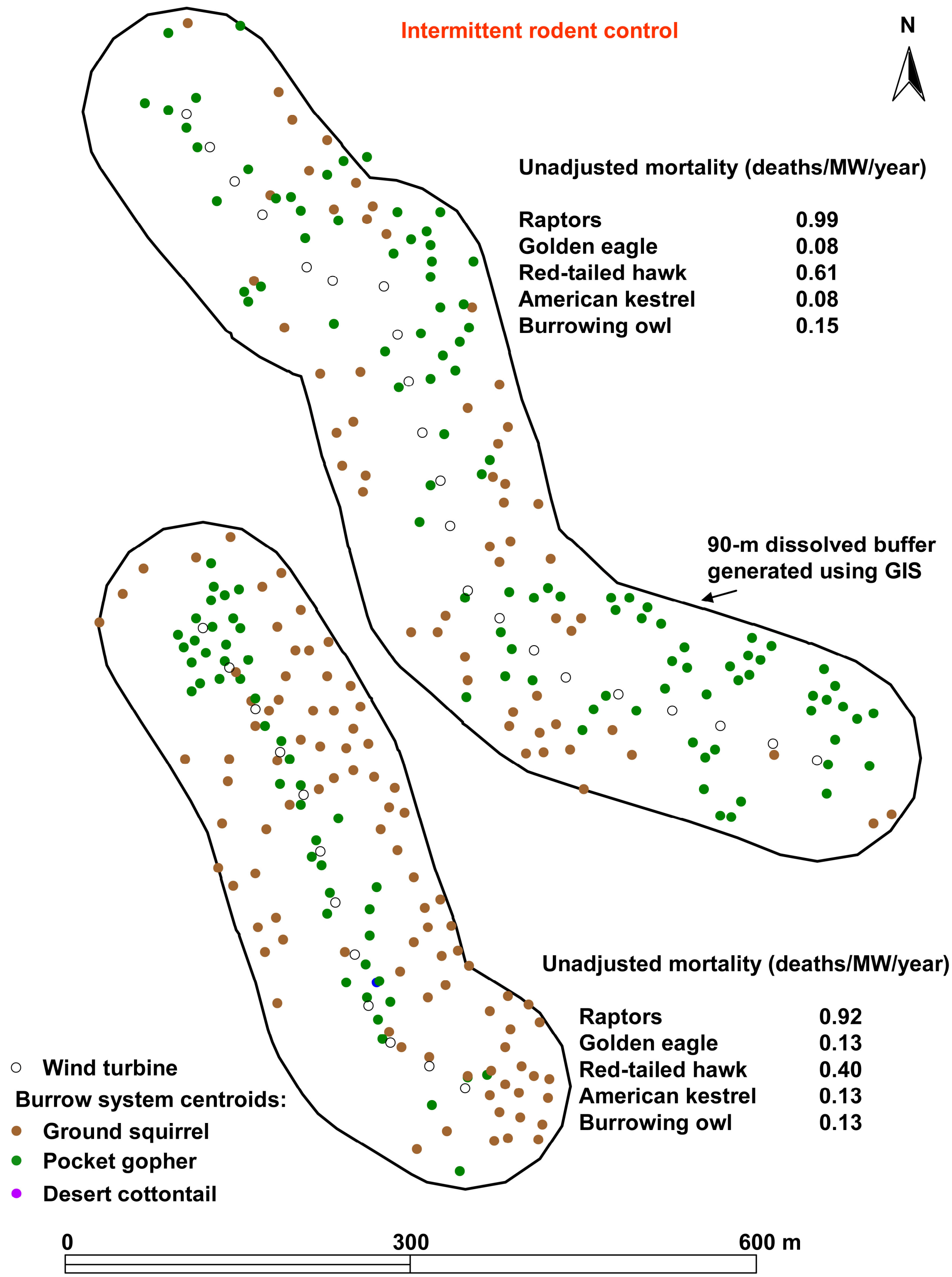
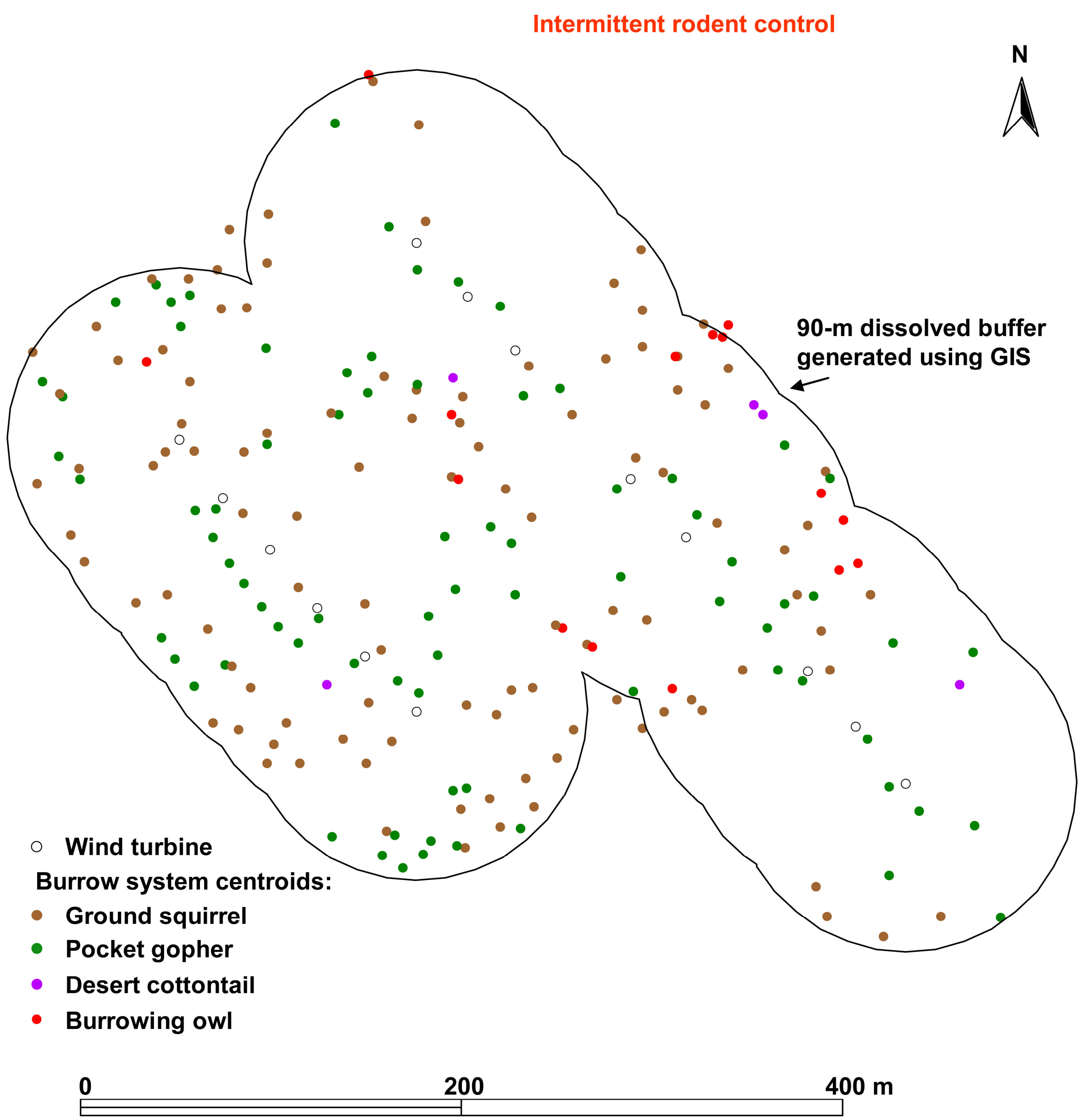


Figure 6-39. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in the northern aspect of EnXco's turbine field and where rodent control was applied intermittently



Unadjusted mortality (deaths/MW/year)

Raptors	0.42
Golden eagle	0.00
Red-tailed hawk	0.14
American kestrel	0.00
Burrowing owl	0.28

Figure 6-40. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in the central aspect of EnXco's turbine field and where rodent control was applied intermittently

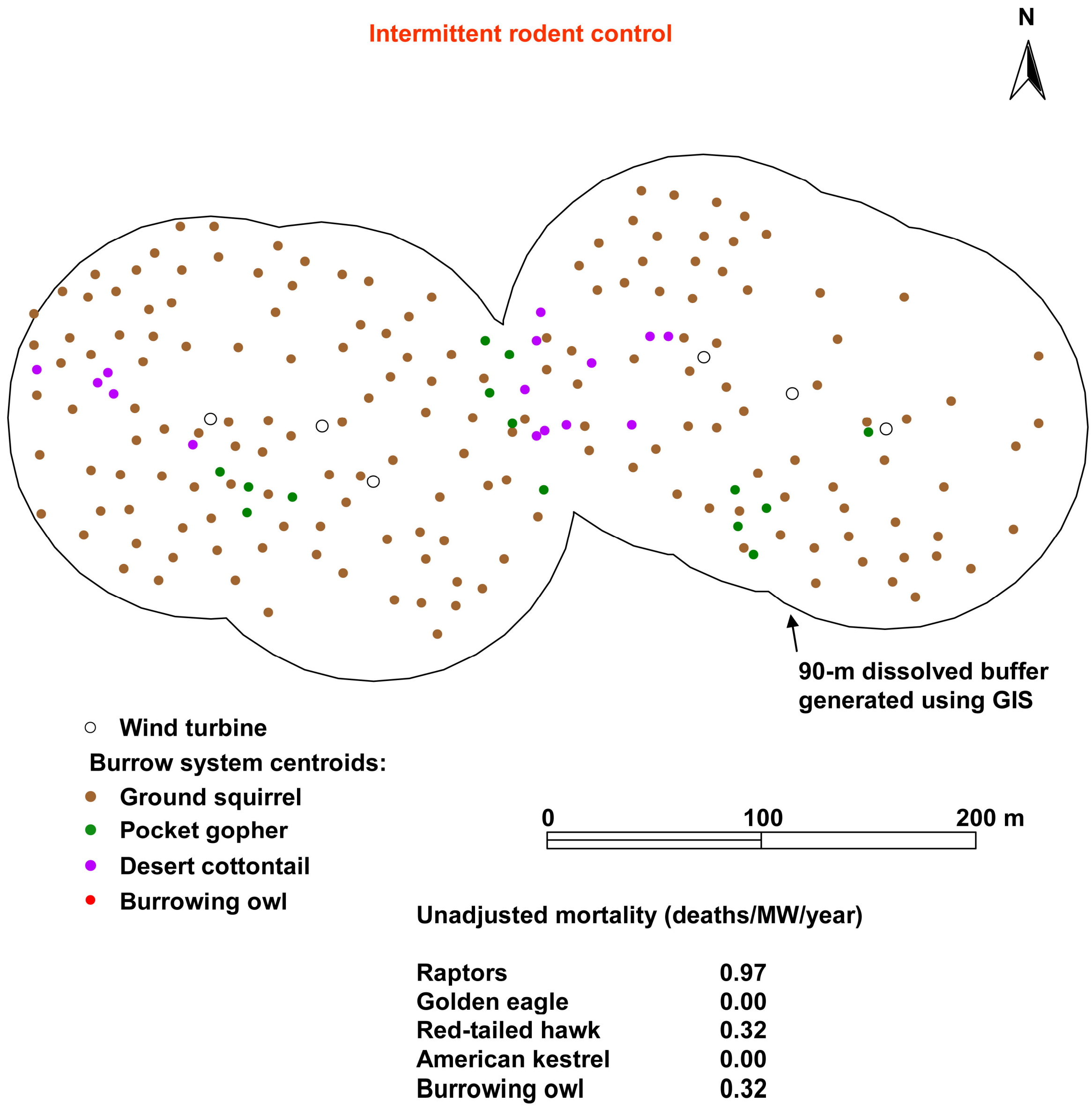


Figure 6-41. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in the southern aspect of EnXco's turbine field, and where rodent control was applied intermittently

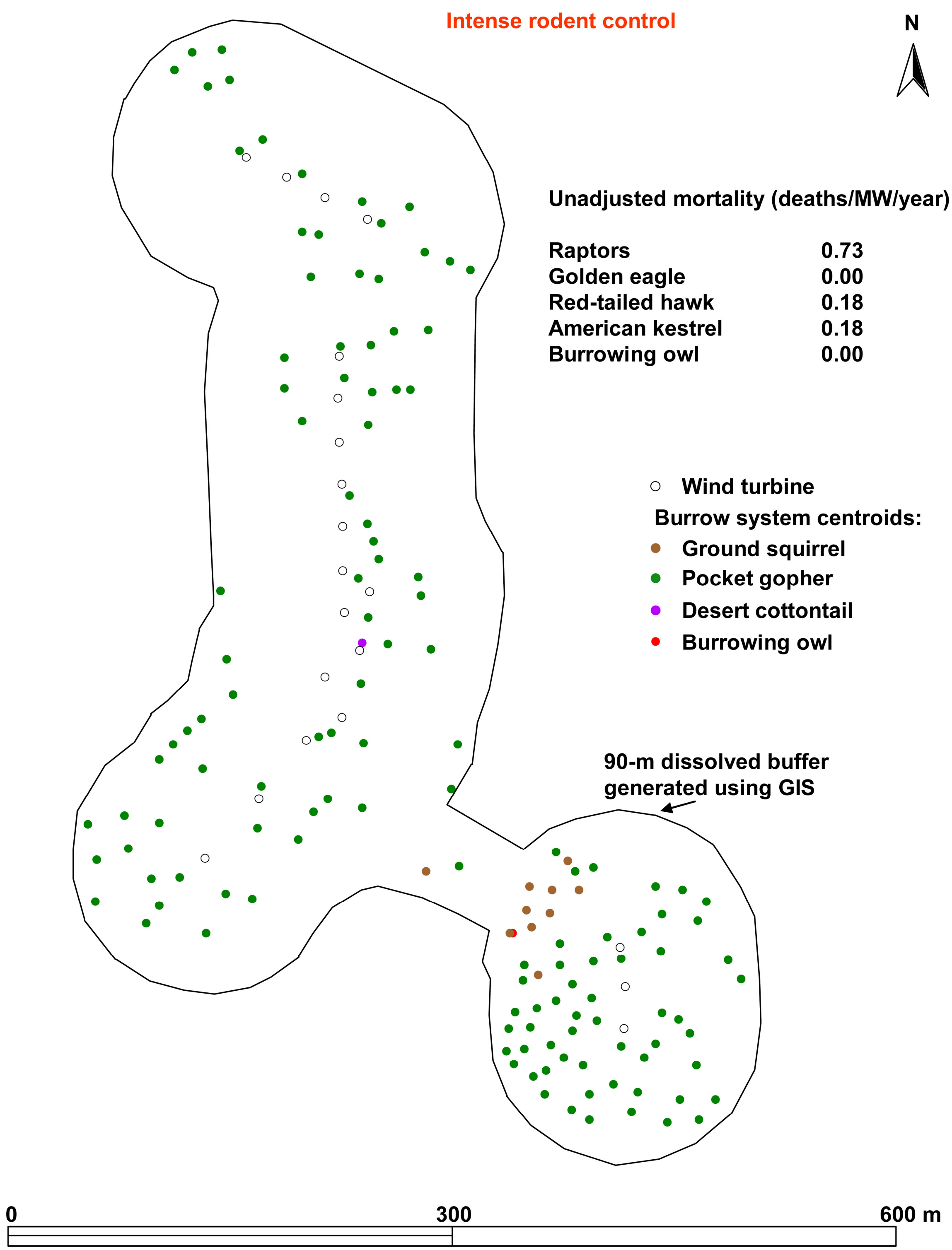


Figure 6-42. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in the Patterson Pass area and where rodent control was applied intensively

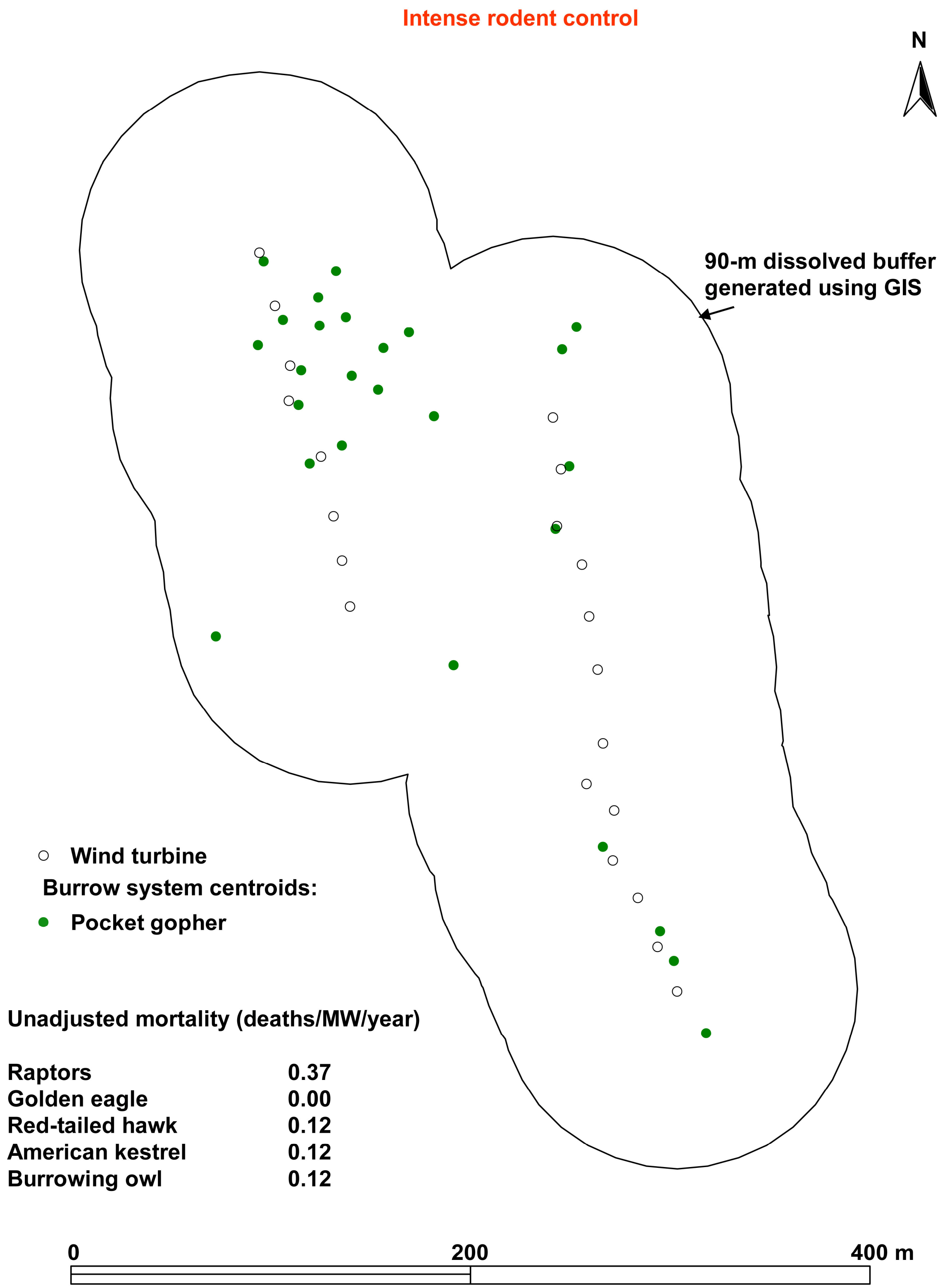


Figure 6-43. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in center of the APWRA, and where rodent control was applied intensively

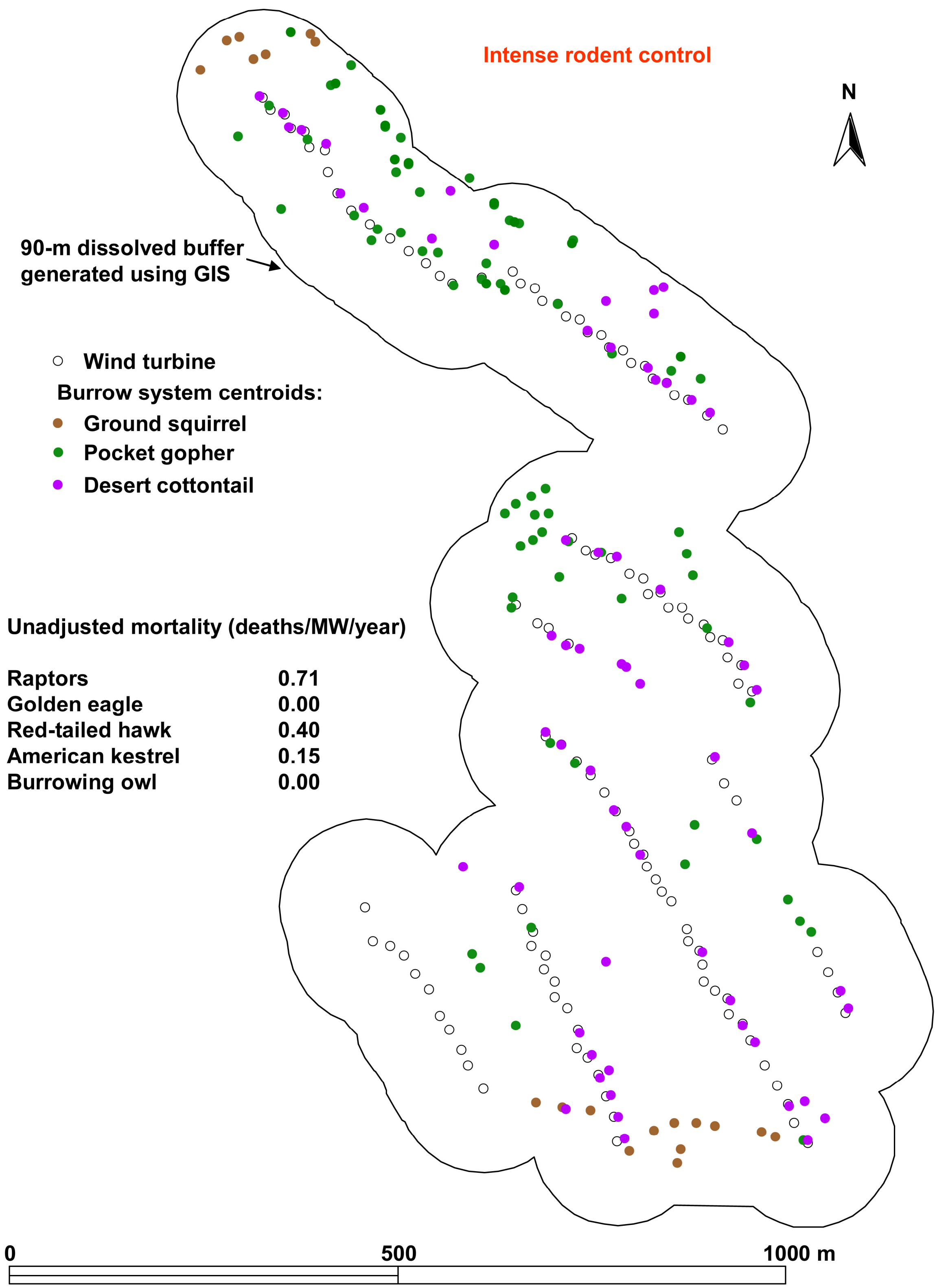


Figure 6-44. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines formerly operated by Enron, and where rodent control was applied intensively

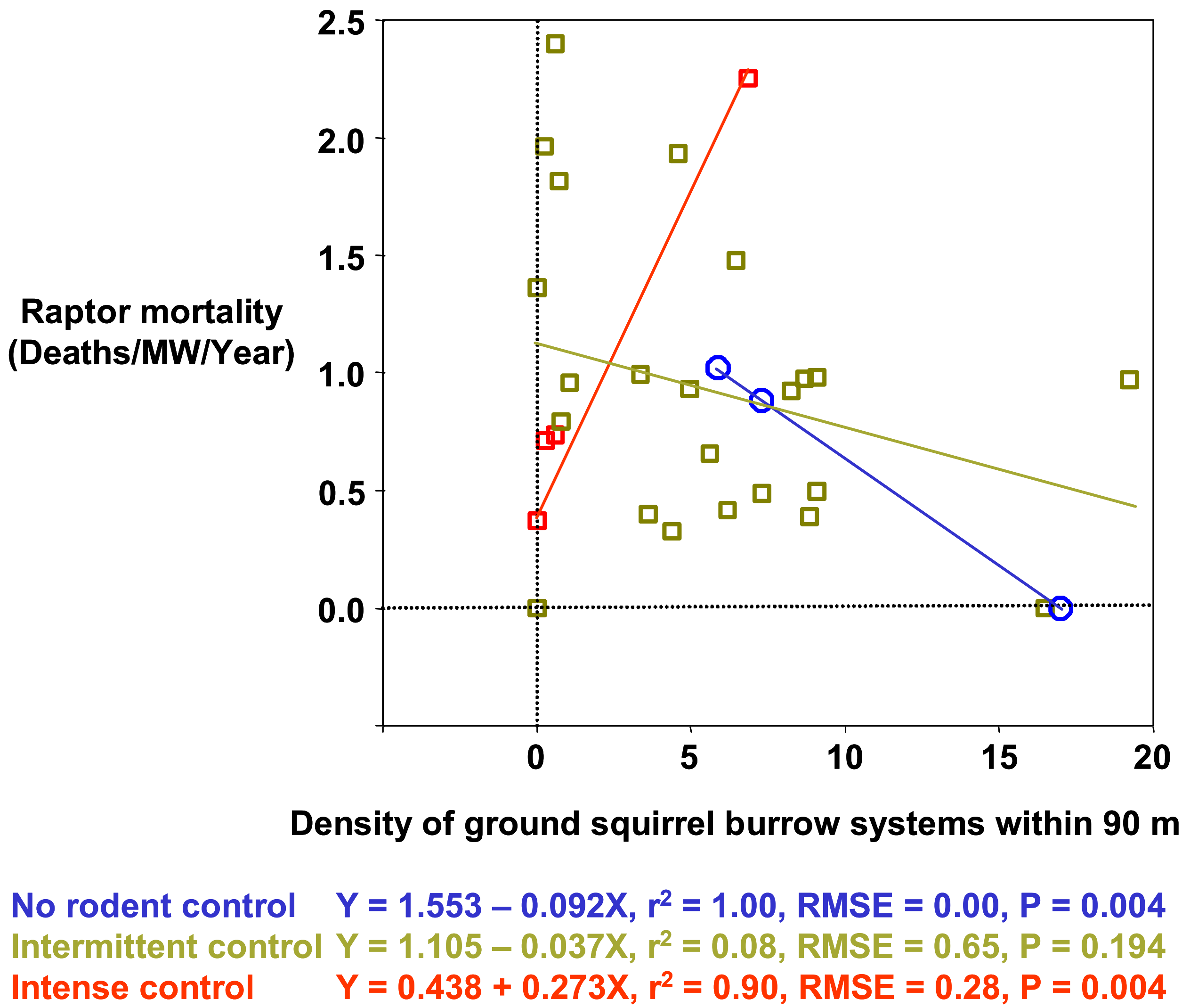


Figure 6-45. Raptor mortality related to the density of ground squirrel burrow systems within 90 m differently depending on rodent control context, increasing with ground squirrel density in areas of intense rodent control, and declining with ground squirrel density in areas of no control

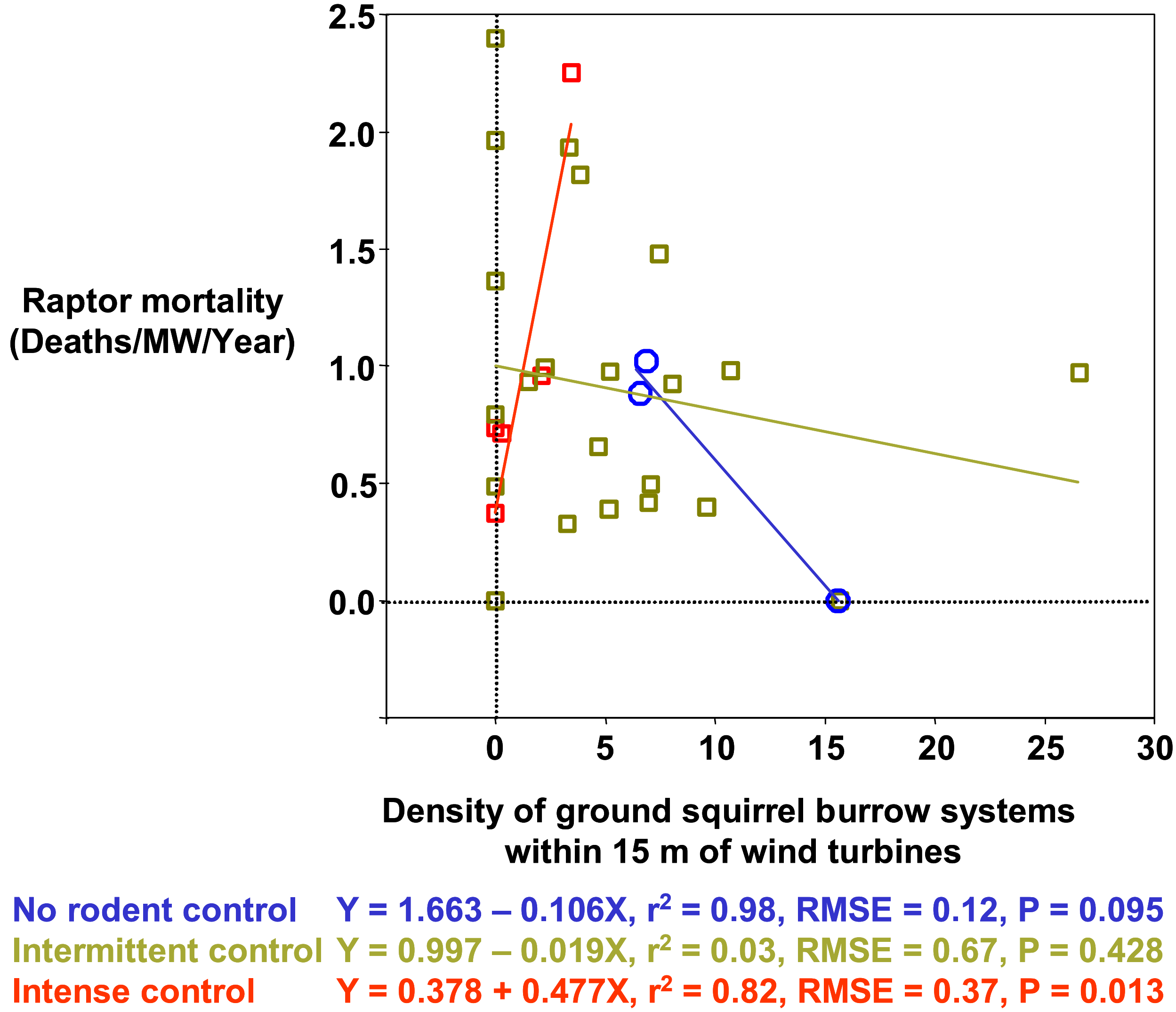


Figure 6-46. Raptor mortality related to the density of ground squirrel burrow systems within 15 m differently depending on rodent control context, increasing with ground squirrel density in areas of intense rodent control, and tending to decline with ground squirrel density in areas of no control

Raptor mortality measured throughout the study period associated significantly with the density of burrow systems of all fossorial species, as well as with the density of burrow systems of ground squirrels out to 90 m (Table 6-2). Mortality was greatest in areas of moderate density of all species and of ground squirrels, and least in areas of highest densities of desert cottontail. It also tended to associate with the degree of clustering of desert cottontail burrows within 15 m of wind turbines relative to within 90 m (Table 6-2), where no desert cottontails within 15 m associated with more raptor fatalities. Raptor mortality was most responsive to intermediate densities of all fossorial species within 15 m of wind turbines, where this attribute could account for 12% of all raptor fatalities.

Table 6-2. Associations between raptors killed throughout the study period and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of all species to 90 m **				
0–5 burrow systems/ha	59	65.67	0.90	-4
5–10 burrow systems/ha	79	59.68	1.32	12
10–22.5 burrow systems/ha	27	39.64	0.68	-8
Density of ground squirrels to 90 m *				
0–2 burrow systems/ha	74	77.28	0.96	-2
3–7 burrow systems/ha	68	54.47	1.25	8
7–19.2 burrow systems/ha	23	33.25	0.69	-6
Clustering of cottontail burrows at turbines ^{t}				
0 burrows/ha	83	70.84	1.17	7
2.6–10.9 burrows/ha	82	93.19	0.88	-7

Raptors killed within a year of the burrow mapping efforts tended to associate with moderate ground squirrel density out to 90 m from wind turbines (Table 6-3). Raptor mortality also tended to associate with highest densities of all fossorial species within 15 m of wind turbines, and associated significantly with the highest densities of pocket gophers within 15 m of wind turbines and lowest desert cottontail densities in this zone (Table 6-3). Raptor mortality within a year of burrow mapping was most responsive to high pocket gopher density within 15 m of wind turbines, where this attribute could account for 17% of all near-term raptor fatalities.

Golden eagle mortality throughout the study period associated significantly with the density of burrow systems of all fossorial species out to 90 m, and it was most responsive to intermediate density of burrow systems. This intermediate density of burrow systems of all fossorial species could account for 37% of all golden eagle fatalities in the sample (Table 6-4). Golden eagle mortality also associated with greater densities of pocket gophers out to 90 m from wind turbines and with the absence of desert cottontails within 15 m of wind turbines (Table 6-4).

In comparison, golden eagles killed within one year of the burrow mapping efforts tended to associate with intermediate pocket gopher densities out to 90 m (Table 6-5). Golden eagle kills were most responsive to the absence of desert cottontails within 15 m of wind turbines, where this attribute could account for 46% of all near-term golden eagle fatalities in the sample. However, we had only a small sample of golden eagle fatalities found within a year of burrow mapping.

Table 6-3. Associations between raptors killed within a year of burrow mapping and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of ground squirrels to 90 m [t]				
0–2 burrow systems/ha	32	34.19	0.94	-3
3–7 burrow systems/ha	35	27.07	1.29	10
7–19.2 burrow systems/ha	9	14.74	0.61	-8
Density of desert cottontails to 90 m *				
0 burrows/ha	29	21.30	1.36	10
0.2–0.7 burrows/ha	35	33.54	1.04	2
0.8–1.7 burrows/ha	12	21.16	0.57	-12
Density of all species to 15 m [t]				
0–10 burrow systems/ha	35	39.99	0.88	-7
10–17 burrow systems/ha	23	25.30	0.91	-3
18–45 burrow systems/ha	18	10.71	1.68	10
Density of pocket gophers to 15 m **				
0–4 burrow systems/ha	34	40.32	0.84	-8
5–12 burrow systems/ha	14	20.84	0.67	-9
13–37 burrow systems/ha	28	14.84	1.89	17
Density of desert cottontails to 15 m *				
0 burrows/ha	41	29.18	1.41	16
0.4–1.7 burrows/ha	19	21.43	0.89	-3
2.3–4.7 burrows/ha	16	25.40	0.63	-12
Clustering of ground squirrels at turbines [t]				
0 burrow systems/ha	19	13.19	1.44	8
0.3–1.0 burrow systems/ha	35	43.68	0.80	-11
1.1–5.2 burrow systems/ha	22	18.57	1.19	5
Clustering of desert cottontails at turbines **				
0 burrows/ha	41	28.61	1.43	16
2.6–10.9 burrows/ha	35	46.82	0.75	-16

Table 6-4. Associations between golden eagles killed throughout the study period and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of all species to 90 m *				
0–5 burrow systems/ha	1	4.38	0.23	-31
5–10 burrow systems/ha	8	3.98	2.01	37
10–22.5 burrow systems/ha	2	2.64	0.76	-6
Density of pocket gophers to 90 m *				
0–2 burrow systems/ha	1	4.95	0.20	-36
2–4 burrow systems/ha	6	2.98	2.01	27
4.3–7.6 burrow systems/ha	4	3.06	1.31	9
Clustering of desert cottontails at turbines *				
0 burrows/ha	8	4.72	1.69	30
2.6–10.9 burrows/ha	3	6.21	0.48	-29

Table 6-5. Associations between golden eagles killed within a year of burrow mapping and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of pocket gophers to 90 m ^{t}				
0–2 burrow systems/ha	1	2.98	0.34	-33
2–4 burrow systems/ha	4	1.48	2.69	42
4.3–7.6 burrow systems/ha	1	1.54	0.65	-9
Density of desert cottontails to 15 m ^{t}				
0 burrows/ha	5	2.30	2.17	45
0.4–1.7 burrows/ha	0	1.69	0	-28
2.3–4.7 burrows/ha	1	2.00	0.50	-17
Clustering of desert cottontails at turbines *				
0 burrows/ha	5	2.26	2.21	46
2.6–10.9 burrows/ha	1	3.70	0.27	-45

Red-tailed hawk mortality measured throughout the study period associated significantly with the density of all fossorial species within 90 m of wind turbines, where intermediate densities could account for 10% of all red-tailed hawk fatalities in our sample (Table 6-6). It was also significantly greater in areas of low to intermediate ground squirrel densities within 90 m of wind turbines, and at wind turbines with lower desert cottontail densities within 15 m (Table 6-6). Red-tailed hawk mortality correlated positively with clustering of burrow systems of all species studied at wind turbines ($r_p = 0.50$, $n = 32$, $P < 0.01$), and tended to correlate with the clustering of pocket gopher burrow systems at wind turbines ($r_p = 0.33$, $n = 32$, $P < 0.10$).

Table 6-6. Associations between red-tailed hawks killed throughout the study period and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of all species to 90 m *				
0–5 burrow systems/ha	35	32.64	1.07	3
5–10 burrow systems/ha	38	29.66	1.28	10
10–22.5 burrow systems/ha	9	19.70	0.46	-13
Density of ground squirrels to 90 m [t]				
0–2 burrow systems/ha	42	38.41	1.09	4
3–7 burrow systems/ha	32	27.07	1.18	6
7–19.2 burrow systems/ha	8	16.52	0.48	-10
Density of desert cottontails to 15 m *				
0 burrows/ha	46	35.69	1.29	13
0.4–1.7 burrows/ha	10	18.50	0.54	-10
2.3–4.7 burrows/ha	26	27.82	0.93	-2
Clustering of desert cottontails at turbines *				
0 burrows/ha	46	35.20	1.31	13
2.6–10.9 burrows/ha	36	46.31	0.78	-13

Red-tailed hawk mortality measured within a year of burrow mapping efforts was significantly greater at turbines lacking desert cottontails out to 90 m, and it was significantly greater at wind turbines with higher densities of all species within 15 m of wind turbines, and especially of pocket gophers within 15 m (Table 6-7). It was also greater where desert cottontails were lacking within 15 m of wind turbines (Table 6-7). It was most responsive to pocket gopher density within 15 m of wind turbines, which accounted for 32% of the near-term red-tailed hawk fatalities in our sample. Measured within a year of the date upon which burrows were mapped, red-tailed hawk mortality also correlated with clustering of burrow systems of all species studied at wind turbines ($r_p = 0.55$, $n = 32$, $P < 0.01$), and correlated with the clustering of pocket gopher burrow systems at wind turbines ($r_p = 0.43$, $n = 32$, $P < 0.05$).

Table 6-7. Associations between red-tailed hawks killed within a year of burrow mapping and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of desert cottontails to 90 m *				
0 burrows/ha	16	9.25	1.73	20
0.2–0.7 burrows/ha	13	14.56	0.89	-5
0.8–1.7 burrows/ha	4	9.19	0.44	-16
Density of all species to 15 m **				
0–10 burrow systems/ha	14	17.37	0.81	-10
10–17 burrow systems/ha	7	10.99	0.64	-12
18–45 burrow systems/ha	12	4.65	2.58	22

Table 6-7. (cont'd)

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of pocket gophers to 15 m **				
0–4 burrow systems/ha	13	17.51	0.74	-14
5–12 burrow systems/ha	3	9.05	0.33	-18
13–37 burrow systems/ha	17	6.45	2.64	32
Density of desert cottontails to 15 m *				
0 burrows/ha	21	12.67	1.66	25
0.4–1.7 burrows/ha	7	9.30	0.75	-7
2.3–4.7 burrows/ha	5	11.03	0.45	-18
Clustering of desert cottontails at turbines **				
0 burrows/ha	21	12.42	1.69	26
2.6–10.9 burrows/ha	12	20.33	0.59	-25

American kestrel mortality measured throughout the study tended to be least where pocket gopher density out to 90 m was also least, and this level of pocket gopher density could account for 23% of the American kestrel fatalities in our sample (Table 6-8).

American kestrel mortality measured within a year of burrow mapping efforts tended to be greatest where pocket gophers were fewest within 90 m and where there was an intermediate level of clustering of desert cottontails within 15 m of wind turbines (Table 6-9). Scarcity of pocket gophers could account for 39% of the near-term American kestrel fatalities in our sample.

Table 6-8. Associations between American kestrels killed throughout the study period and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of pocket gophers to 90 m ^{t}				
0–2 burrow systems/ha	13	8.55	1.52	23
2–4 burrow systems/ha	1	5.15	0.19	-22
4.3–7.6 burrow systems/ha	5	5.29	0.94	-2
Clustering of desert cottontails at turbines ^{t}				
0 burrows/ha	4	8.16	0.49	-22
2.6–10.9 burrows/ha	15	10.73	1.40	22

Table 6-9. Associations between American kestrels killed within a year of burrow mapping and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of pocket gophers to 90 m [t]				
0–2 burrow systems/ha	8	4.47	1.79	39
2–4 burrow systems/ha	0	2.23	0	-25
4.3–7.6 burrow systems/ha	1	2.31	0.43	-15
Clustering of all species at turbines [t]				
0–1.25 obs/expected burrows ≤ 15 m	0	1.72	0	-19
1.26–2.00 obs/expected burrows ≤ 15 m	6	3.04	1.97	33
2.01–7.19 obs/expected burrows ≤ 15 m	3	4.17	0.72	-13

Burrowing owl mortality measured throughout the study was greater at wind turbines surrounded by higher densities of all fossorial species within 90 m, but especially with intermediate densities (Table 6-10). It was disproportionately greater at wind turbines with intermediate densities of ground squirrel and desert cottontail burrow systems within 90 m, and it tended to be greater at the highest densities of ground squirrel burrow systems within 15 m of wind turbines (Table 6-10). It was also significantly greater at wind turbines with burrowing owl burrows located within 90 m, and the occurrence of these burrows could account for 23% of the burrowing owl fatalities in our sample (Table 6-10).

Burrowing owl mortality measured within a year of burrow mapping efforts also was greatest at turbines with intermediate densities of burrow systems of all fossorial species within 90 m, and these densities could account for 43% of the variation in burrowing owl fatalities in our sample (Table 6-11). It tended to be greater at highest ground squirrel densities within 15 m of wind turbines and was significantly greater where desert cottontails were absent within 90 m and within 15 m (Table 6-11). Near-term burrowing owl mortality was significantly greater at wind turbines with burrowing owl burrows within 90 m, and this condition could account for 28% of the fatalities in our sample (Table 6-11).

Table 6-10. Associations between burrowing owls killed throughout the study period and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of all species to 90 m *				
0–5 burrow systems/ha	4	10.75	0.37	-25
5–10 burrow systems/ha	15	9.77	1.54	19
10–22.5 burrow systems/ha	8	6.49	1.23	6
Density of ground squirrels to 90 m **				
0–2 burrow systems/ha	5	12.65	0.40	-28
3–7 burrow systems/ha	17	8.91	1.91	30
7–19.2 burrow systems/ha	5	5.44	0.92	-2
Density of desert cottontails to 90 m ^{t}				
0 burrows/ha	9	8.75	1.03	1
0.2–0.7 burrows/ha	15	10.10	1.49	18
0.8–1.7 burrows/ha	3	8.16	0.37	-19
Density of ground squirrels to 15 m ^{t}				
0 burrow systems/ha	2	4.81	0.42	-10
0.3–5.2 burrow systems/ha	14	15.88	0.88	-7
6.6–26.6 burrow systems/ha	11	6.30	1.75	17
Clustering of ground squirrels at turbines *				
0 burrow systems/ha	2	4.65	0.43	-10
0.3–1.0 burrow systems/ha	13	16.76	0.78	-14
1.1–5.2 burrow systems/ha	12	5.43	2.21	24
Density of burrowing owls to 90 m *				
0 burrows/ha	12	18.16	0.66	-23
0.02–0.88 burrows/ha	15	8.84	1.70	23

Table 6-11. Associations between burrowing owls killed within a year of burrow mapping and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of ground squirrels to 90 m **				
0–2 burrow systems/ha	2	6.30	0.32	-31
3–7 burrow systems/ha	11	4.99	2.21	43
7–19.2 burrow systems/ha	1	2.72	0.37	-12
Density of desert cottontails to 90 m *				
0 burrows/ha	7	3.92	1.78	22
0.2–0.7 burrows/ha	7	6.18	1.13	6
0.8–1.7 burrows/ha	0	3.90	0	-28
Density of ground squirrels to 15 m ^{t}				
0 burrow systems/ha	2	2.53	0.79	-4
0.3–5.2 burrow systems/ha	4	7.49	0.53	-25
6.6–26.6 burrow systems/ha	8	3.98	2.01	29
Density of desert cottontails to 15 m *				
0 burrows/ha	9	5.37	1.67	26
0.4–1.7 burrows/ha	5	3.95	1.27	8
2.3–4.7 burrows/ha	0	4.68	0	-33
Clustering of all species at turbines ^{t}				
0–1.25 obs/expected burrows ≤ 15 m	0	2.67	0	-19
1.26–2.00 obs/expected burrows ≤ 15 m	8	4.73	1.69	23
2.01–7.19 obs/expected burrows ≤ 15 m	6	6.49	0.92	-4
Clustering of ground squirrels at turbines ^{t}				
0 burrow systems/ha	2	2.43	0.82	-3
0.3–1.0 burrow systems/ha	5	8.05	0.62	-22
1.1–5.2 burrow systems/ha	7	3.42	2.05	26
Clustering of desert cottontails at turbines *				
0 burrows/ha	9	5.27	1.71	27
2.6–10.9 burrows/ha	5	8.63	0.58	-26
Density of burrowing owls to 90 m *				
0 burrows/ha	5	8.88	0.56	-28
0.02–0.88 burrows/ha	9	5.12	1.76	28

6.3.5 Relationships Between Bird Mortality and Rodent Control

Burrowing owl mortality was significantly greater on the ranch where rodent control was intermittently applied (Table 6-12). However, the mortality of every other species except mallard did not relate significantly to intensity of rodent control. Most likely the mallard's significant relationship of mortality with rodent control intensity was only spurious, because it is difficult to explain how rodent control would affect mallard mortality.

6.4 DISCUSSION

Our study refutes several hypotheses about the relationships between wind turbines, rodent control, and rodent distribution and abundance. For example, it appears that ground squirrel distribution was not extended by the wind turbine access roads or disturbed soils related to the wind farm at the Altamont Pass, as had been suggested by Colson (1995) and Morrison (1996). In fact, ground squirrels appear to avoid the 15-m zone around the wind turbines, which is where the access roads and soil disturbances principally occur. Pocket gophers, however, were attracted to this zone where soils were disturbed, and this species typically occurred there two to four times more often than expected by a uniform distribution of gopher burrow systems within the entire search area.

Table 6-12. Summary of mortality estimates by rodent control intensity in the APWRA from May 1998 through September 2002

Species or Taxonomic group	Mean mortality (fatalities/MW/year)				
	Rodent control through 2002			ANOVA F-value (df = 2,445)	P-value
	None (120 strings, 118.02 MW)	Intermittent 87 strings, 65.33 MW)	Intense (240 strings, 206.3 MW)		
Golden eagle	0.1267	0.0709	0.1037	0.10	0.901
Red-tailed hawk	0.3747	0.3095	0.2164	0.69	0.504
American kestrel	0.1317	0.0561	0.1010	5.14	0.599
Burrowing owl	0.0137	0.1632	0.0871	4.45	0.012
Great horned owl	0.0144	0.0053	0.0152	0.31	0.737
Barn owl	0.0456	0.0984	0.0286	1.82	0.165
Mallard	0.0059	0.1034	0.0303	3.26	0.039
Rock dove	0.4631	0.2939	0.1823	2.43	0.089
European starling	0.1149	0.0361	0.1864	0.94	0.393
Horned lark	0.0134	0.0238	0.0188	0.25	0.782
Western meadowlark	0.1727	0.1500	0.2559	0.42	0.649
House finch	0.0000	0.0361	0.0266	1.32	0.268
Raptor	1.2092	1.1359	1.0346	0.23	0.793
TOTAL	2.0123	1.6827	1.6746	0.41	0.665

Hunt (2002) accurately predicted that ground squirrel control would reduce the abundance of ground squirrels. On lands with intense rodent control, almost no ground squirrel burrow systems remain. But on a ranch where rodent control was applied less intensively, ground squirrel abundance increased from 1999 through 2001. This result is not consistent with what was expected to occur there.

Each year we witnessed the applications of the poison bait on portions of the APWRA. We observed high mortality of ground squirrels and desert cottontails, whose carcasses lay upon the ground or in rock piles and were scavenged by raptors. The remains or odors associated with dead animals were openly evident during the two weeks following the poison bait applications. However, despite our observations of widespread mortality of squirrels due to control implemented intermittently on one particular ranch, the density of ground squirrel burrow systems increased from 1999 through 2001. We believe that subadult ground squirrels quickly immigrated from surrounding areas, or from unaffected colonies on this ranch, and occupied the abandoned burrow systems.

Intermittent rodent control associated with an increased density of pocket gopher burrow systems out to 90 m from the wind turbines and with increased degrees of clustering of gopher burrow systems around the wind turbines. Pocket gopher density and distribution responded to rodent control almost opposite the density and distribution of ground squirrels; whereas ground squirrel density and degree of clustering decreased in areas of rodent control, the density and degree of clustering of pocket gophers increased. The response of pocket gophers may be an unintended consequence of the rodent control program in the APWRA, and this consequence may exacerbate the bird mortality problem by effectively concentrating sign of fossorial rodents among wind turbines because sign is removed from locations farther away from the wind turbines. The response of pocket gophers to the rodent control program was consistent with this species' responses to abatement efforts in forest clear cuts (Smallwood 1999) and in alfalfa stands (Smallwood et al. 2001), again demonstrating that a simplistic abatement approach may not achieve desired results due to the ecological complexity of this species.

The significant correlation between pocket gopher burrow system clustering at wind turbines and cattle pat abundance may indicate a complex ecological relationship in which cattle more intensively use some wind turbines for shade and consequently where they more intensively graze down the grass and defecate. The increased abundance of cattle pats near these wind turbines may fertilize plants to the advantage of forbs, including leguminous plants, which appear to flourish near wind turbines. Pocket gophers may be attracted to the near-zone of wind turbines partly due to the food plants available there. Cattle pats also create concentrations of grasshoppers and other prey items for smaller raptors such as burrowing owls and American kestrels. Also, several *Buteo* species such as red-tailed hawks and Swainson's hawks are known to gorge on grasshoppers when they are extraordinarily abundant.

Table 6-13 summarizes the significant relationships we found between small mammal burrow systems and variables measured in this study. The distribution and abundance of small mammal species in the APWRA, and the underlying reasons for their distribution and abundance, are more complicated than previously imagined. Our study certainly did not fully characterize the factors affecting small mammal distribution and abundance. In the field we observed many tantalizing indicators suggesting larger patterns that warrant further investigation, but for which we lacked the time and resources to pursue. For example, we observed desert cottontails burrowing under wind turbine pads (Photo 6-5), but we did not have the opportunity to identify, and therefore more widely characterize, the conditions associated with this burrowing activity.

Table 6-13. Summary of significant relationships between factors measured in our study and small mammal distribution and abundance

Dependent Variable	Magnitude and Direction of Significant Effects
Pocket gopher clustering at turbines	3.4 × greater in areas of intermediate control
	increased with percent of wind turbines in canyon (r = 0.27)
	decreased with more desert cottontail fecal pellets (r = -0.32)
	increased with more cattle pats 20-40 m from turbines (r = 0.49)
	increased with more cattle pats along turbine string (r = 0.51)
	3 × greater on west and southwest slopes
Ground squirrel clustering at turbines	decreased with greater elevation (r = -0.32)
	increased with more cattle pats along turbine string (r = 0.34)
Desert cottontail clustering at turbines	3.6 × less in areas of intermittent rodent control
Pocket gopher density within 15 m	12 × greater in areas of intermittent rodent control
Pocket gopher density within 90 m	2 × greater in areas of intermittent rodent control
Ground squirrel density within 15 m	10 × in areas of no control compared to intense control
Ground squirrel density within 90 m	6.7 × in areas of no control compared to intense control

Photo 6-5. Desert cottontails burrowed under some wind turbine pads.

Based on the inter-annual comparisons of mortality presented in Chapter 3, there was no compelling evidence that the rodent control program succeeded in reducing mortality of raptors or all birds. Even for those species and species groups for which significant decreases in mortality occurred during the study, they were preceded by significant increases in mortality during a time period several years into the rodent control program. Also, the implementation of rodent control at the SeaWest-owned turbines failed to cause declines in raptor mortality by the end of the first year of the program (2002).

Based on the analysis of data presented in this chapter, rodent control does not appear to reduce raptor use of the APWRA and, therefore, it is not an effective tool for reducing raptor mortality. The spatial distribution of an animal species is influenced by multiple factors, including the strong effects of social organization, which are rather rigid and unresponsive to local changes in the distribution and abundance of prey items (Smallwood 2002). Smallwood (2002) summarized cases where animal species were shown to rely more on gestalt and sociality in spacing themselves out in their environment, and to not always rely upon prey enumeration.

We found that raptor mortality was greater in areas with intermediate densities of ground squirrel burrow systems within 90 m, as well as with intermediate densities of burrow systems of all fossorial mammal species. It was greater at wind turbines with greatest densities of pocket gopher burrow systems within 15 m, which also corresponded with areas subjected to intermittent rodent control. These patterns were true for mortality of golden eagle, red-tailed hawk, and more or less for burrowing owl.

Burrowing owl mortality was greater where burrowing owls resided within 90 m of wind turbines. It is possible that burrowing owls more often reside near wind turbines following poisoning of ground squirrels because the vacated burrows will be more available to burrowing owls. Repetitive intense control would likely eliminate this pattern, however, because vacant squirrel burrows eventually collapse and become unavailable to burrowing owls. In fact, we did not find evidence of burrowing owl residency of burrows within the areas of intense control.

During the period of our study, consultants contracted by the owners performed and reported on an investigation of rodenticide use in relation to golden eagle and red-tailed hawk fatalities. Our results differ significantly with those reported in Kerlinger and Curry (2003), who concluded that the rodent control program has achieved its objectives by reducing raptor mortality. The reasons for our differences in results are summarized in Appendix B.

Even had the monitoring and experimental design of the Kerlinger and Curry (2003) study not been flawed (see Appendix B), the conflicting results presented by the owner's consultants is further evidence that the rodent control program is not meeting its goal. Kerlinger and Curry (2003) reported mortality estimates generated from the WRRS during the time period 1989 to 2002 that were 1.7 times greater for red-tailed hawk and 2.3 times greater for golden eagle than Kerlinger and Curry (1998) reported for the time period 1989 to 1991.

We note that the longer time period of the WRRS includes the shorter, earlier time period of 1989–1991, so the increase in mortality must have been even greater than 1.7- and 2.3-fold for red-tailed hawk and golden eagle, respectively. However, Kerlinger and Curry (1998) reported nearly identical mortality estimates for red-tailed hawk and golden eagle during 1989 to 1997 as Kerlinger and Curry (2003) reported for the period 1989 to 2002. They reported 0.00581 golden eagles/turbine/year during the entire period compared to 0.00602 golden eagles/turbine/year during the period ending in 1997, or an increase of 0.7 (3.5%) golden eagles per year, including the last five years. They reported 0.0101 red-tailed hawks/turbine/year during the entire period, compared to 0.01081 red-tailed hawks /turbine/year during the period ending in 1997, or a decrease of 2.4 (6.8%) red-tailed hawks per year, including the last five years. These comparisons refute claims that the rodent control program has reduced raptor mortality.

In addition, rodent control likely threatens four special-status species commonly observed in the APWRA. Two such species are the California red-legged frog (Photo 6-6) and the California tiger salamander, both listed as threatened under the federal Endangered Species Act (Photo 6-7). These species are losing fossorial mammal burrows as refuge sites, while the rodent control proceeds to reduce the abundance and distribution of small mammals. Rodent control also threatens the existence of the endangered San Joaquin kit fox, a species for which use was last documented in the APWRA during the early 1990s (Photo 6-8). San Joaquin kit fox are sensitive to anti-coagulant poisons such as the chlorophacinone being used in the APWRA. The loss of ground squirrel burrow systems to rodent control also depletes a critical habitat element of burrowing owl, which is a Species of Special Concern in California.

Photo 6-6. A California red-legged frog found in the APWRA (photo by Brian Karas)

Photo 6-7. A California tiger salamander found in the APWRA (photo by Brian Karas)

Photo 6-8. The broadcasting of rolled oats laced with chlorophacinone poses a hazard to the San Joaquin kit fox, a species that was documented to use the APWRA. Wind turbine installation in the APWRA originally required mitigation measures for San Joaquin kit fox conservation.

In conclusion, we recommend the cessation of rodent control programs in the APWRA. Research is needed, however, that explores alternative means of managing the spatial distribution of small mammals in the APWRA. Chapter 9 includes suggested alternatives, and other ideas might be found in Van Vuren and Smallwood (1996).

Intermittent rodent control appears to be contributing to greater raptor mortality and might be increasing burrowing owl residency within close proximity to wind turbines. Intense rodent control was associated with fewer golden eagle fatalities in areas of intense rodent control but the association is not strong enough to warrant its continued use. Additionally, golden eagle mortality throughout the APWRA did not change between years when rodent control was conducted. The rodent control efforts effectively reduced small mammal densities but they probably adversely affected four special-status species and other non-sensitive wildlife using the area. They fail to noticeably reduce raptor mortality in general, which was their intended purpose.